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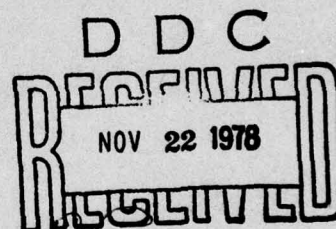
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TECHNICAL REPORT ARBRL-TR-02092

BLAST LOADING ON MODEL EARTH
COVERED MAGAZINES

Charles N. Kingery

August 1978

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20. ABSTRACT *(Continue on reverse side if necessary and identify by block number)* (mba)

This report contains the results obtained from a series of high explosive tests designed to determine the blast loading on scaled models of earth covered munition storage magazines. A 1/30th scaled (non-responding) model was exposed to three charge weights (.454, .908 and 1.135 kg) and a 1/45th scaled model was exposed to a .454 kg charge weight. The objective was to determine the weight, configuration and stand-off distance for an uncovered TNT charge that would produce the pressure and impulse loading obtained from the explosion of a loaded earth covered munition magazine when placed at the side to side safe

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separation distance. A 1/30 scaled model exposed to a 1.135 kg hemispherical pentolite charge at a stand-off distance of 1.6m gave the best model simulation. This will scale, for a full-size test, to a hemispherical charge of TNT weighing 34,050 kg placed 47.2 m from the center line of the acceptor structures.

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I. INTRODUCTION

A. Background

The Department of Defense Explosives Safety Board (DDESB) has for the past five years sponsored scale model studies at the Ballistic Research Laboratory (BRL)[1,2]. This work was sponsored in an effort to supplement and complement, as well as aid in the design of, full scale field tests. It was shown in Reference 2 that blast parameters from scaled models as small as 1/50 the full size storage magazines could be correlated directly with results from full scale tests. With this background knowledge and experience the present test program was planned and executed.

B. Objectives

The primary objective of this project is to furnish information that will aid in the design of a large scale field test. The objectives of the large scale field test are (1) to demonstrate the safety of explosive storage in economically constructed non-circular steel and concrete arch magazines at a minimum side-to-side separation distance and (2) to use a smaller uncovered charge to produce the blast loads generated from a much larger explosive source contained in a standard earth-covered storage magazine similar to the one used in the ESKIMO III test[3]. The planned full-size field test is designated ESKIMO V.

C. Approach

The approach to meet the primary objective was first to meet the following secondary objectives:

1. Design the scale model structure.

2. Establish the charge configuration.

3. Establish the charge.

4. Establish the instrumentation system.

5. Conduct the test series.

---

[1]R. E. Reisler, L. Giglio-Tos, G. D. Teel, "Air Blast Parameters from Pentolite Cylinders Detonated on the Ground," Ballistic Research Laboratories Memorandum Report No. 2471, April 1975. (AD #B003883L)

[2]C. N. Kingery, G. A. Coulter, G. T. Watson, "Blast Parameters from Explosions in Model Earth Covered Magazines," Ballistic Research Laboratories Memorandum Report No. 2680, September 1976. (AD #A031414)

[3]F. H. Weals, "ESKIMO III Magazine Separative Tests," Naval Weapons Center Report TP-5771, February 1976.

6. Recommend charge weight and location.

7. Predict blast loading on the full-size structures to be exposed on ESKIMO V.

II. TEST PROCEDURE

The test procedures followed to meet the primary objective were those required to meet the secondary objectives noted under Approach.

A. Model Magazine Design

The standard munition storage magazine being scaled for this test series is shown in Figure 1. The overall width is 27.43 metres (90 feet), length 35.05 metres (115 feet) and height 4.88 metres (16 feet). In ESKIMO III the distance between the center line of the donor magazine to the center line of the acceptor magazines was 34.75 metres (114 feet).

From preliminary calculations it appeared that a 13,620 kg (30,000) pound TNT charge would give the required pressure of 5.37 to 6.55 bars (78 - 95 psi) and impulse 44.83 bar-msec (650 psi-msec) over the top of the structure. Based on these preliminary estimates the model scale was established as 1/30. This implies that a .454 kg (1 pound) charge would simulate 12,259 kg (27,000 lb) of explosive. The 1/30 scale model, as designed for this test series, is shown in Figure 2.

In the later phase of the test series it appeared desirable to simulate a 41,370 kg (91,125 lb) TNT charge. Therefore a 1/45 scale model was designed so that blast loading could be simulated with a .454 kg (1 lb) pentolite charge. The dimensions of the 1/45 scale model are shown in Figure 3.

B. Test Charges

Before the test charges could be cast it was first necessary to establish (1) the type of explosive required, (2) the configuration most appropriate, and (3) the weights required.

1. Type of Explosive. The BRL has over the past 25 years established a wealth of basic blast data from pentolite charges. Pentolite is relatively insensitive to shock, making it safe to handle and it gives good repeatability from shot to shot. Although TNT is planned for the full scale test it does not have the repeatability required of the small charge weights. Therefore, pentolite which has a TNT equivalency[4] of 1.17 was selected for use on this program.

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[4] *T-M 5-1300, "Structure to Resist the Effects of Accidental Explosions," Army Manual, June 1969.*

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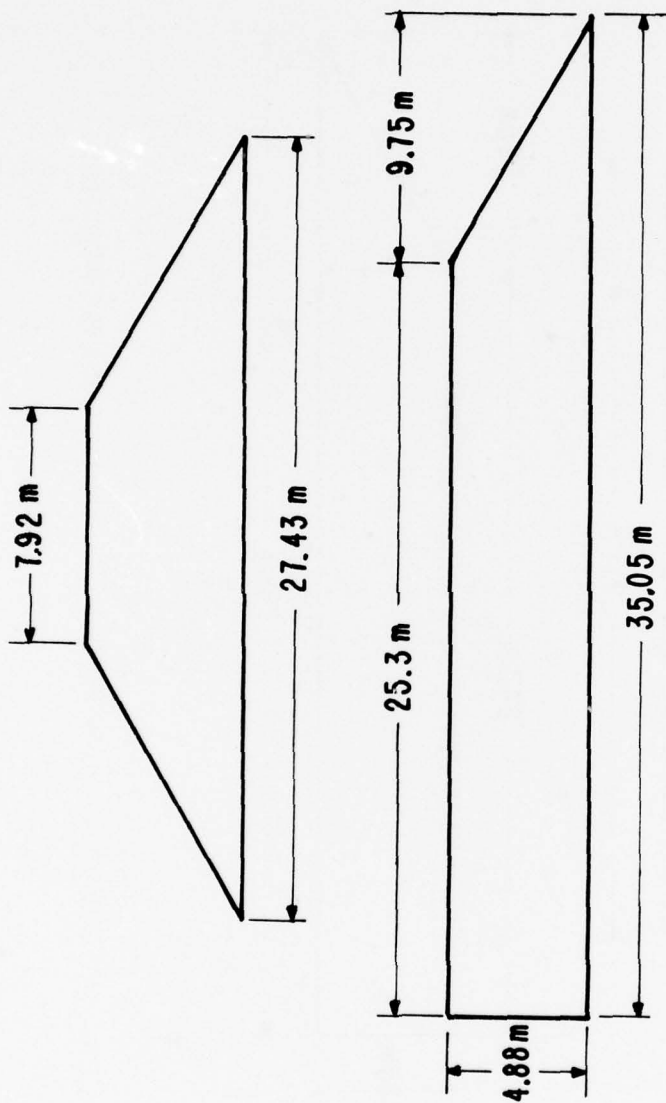
Figure 1. Standard Munition Storage Magazine
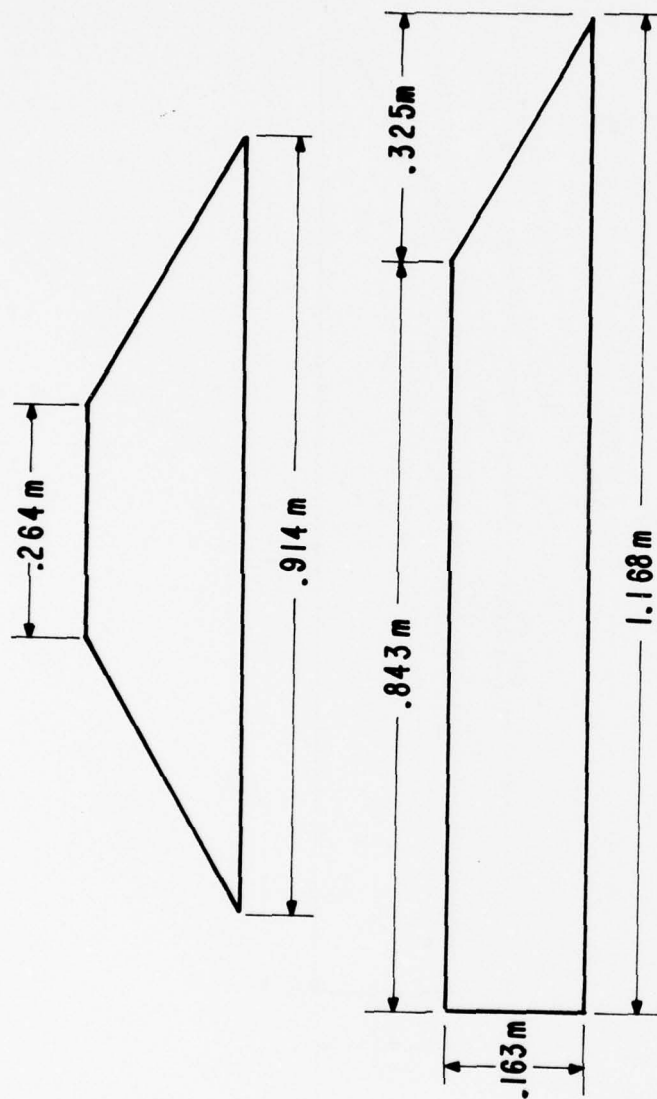
Figure 2. 1/30 Scale Model Munition Storage Magazine

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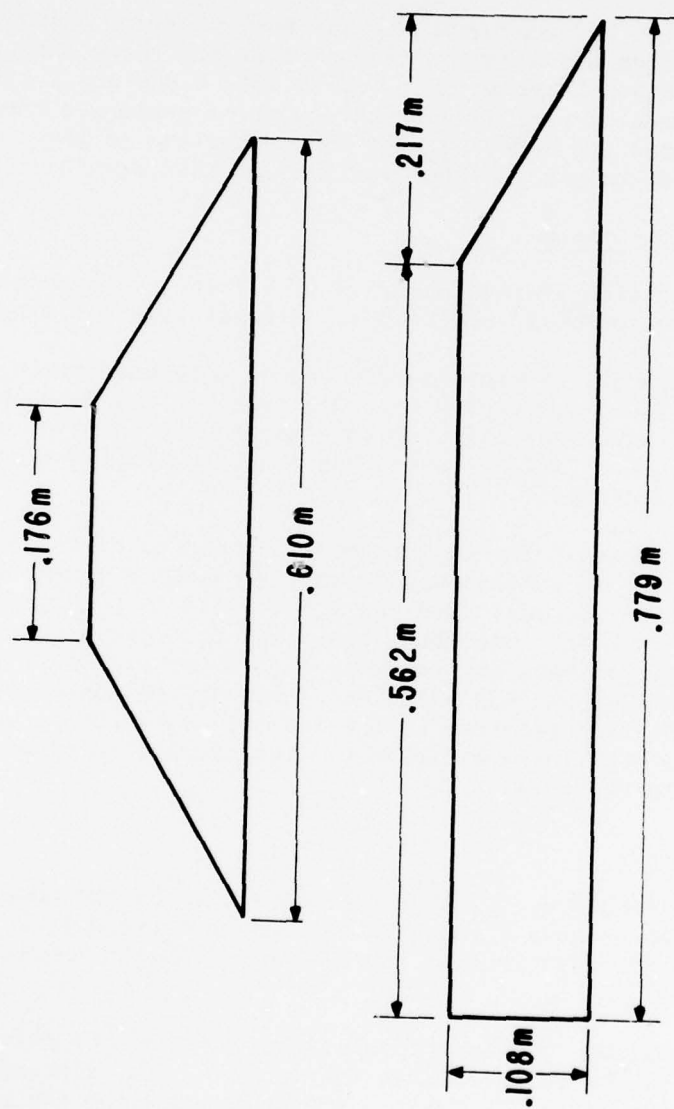
Figure 3. 1/45 Scale Model Munition Storage Magazine

2. **Charge Configuration.** The charge configurations first considered were a hemi-cylinder as used in Reference 2 or a cylindrical charge as used in Reference 1. After plotting the shock profile (iso-pressure and iso-impulse contours) along the 0, 45, 90, 135 and 180 degree lines it became apparent that the loading on a structure would be quite non-symmetric. Therefore, a recommendation was made to the DDESB that a hemispherical charge be considered for the full-size test.

3. **Charge Weights.** The recommendation for hemispherical charges as the donor configuration was accepted and an order for three charge weights was issued. These charge weights were 0.454, 0.908 and 1.135 kg or 1, 2 and 2.5 pounds of pentolite. The amount of explosive these charges will simulate and the location from the centerline of the acceptor magazine are discussed in later sections of this report.

C. Test Instrumentation System

The test instrumentation system consisted of (1) the pressure transducer, (2) the tape recorder with amplifiers, calibration and timing.

1. **Pressure Transducer.** Piezo-electric gauges were used throughout the series of tests. Two types were used. One type was the Susquehanna Instruments Model ST-4 with tourmaline sensors and the second type was a PCB Electronics Inc., Model 113A24 which has a quartz sensing element and a built-in source follower.

2. **Tape Recorder System.** The tape recorder consisted of three basic units - the power supply and voltage calibrator, the amplifier and the FM recorder. The FM tape recorder used was a Honeywell 7600 having a frequency response of 80 k Hz. Once the signal was recorded on the magnetic tape it was played back and recorded on a Honeywell Model 1858 Visrecorder. This oscillograph has excellent frequency response and the overpressure versus time recorder at the individual positions were read directly from the oscillograph playback. The overall instrumentation system is shown in Figure 4.

D. Test Layout

The test layout depended primarily on the selection of the model scale and charge weight because the gage locations on the model are fixed. The charge weight then governs the distance from the charge to a specific model scale.

1. **Full Size Magazine.** The locations of the gages on the full-size structure exposed on ESKIMO III are shown in Figure 5. The distances from the gauge locations listed in Table I are measured along the ground surface to the geometric center of the interior of the donor structure. Also listed in Table I are the peak overpressures and impulses recorded at similar positions on the two acceptor magazines. These values are

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Figure 1. Instrumentation System

13 ▣

12 ▣

11 ▣   ▣ 10 B

6 ▣   ▣ 10 A

5 ▣

2 ▣

34.7 m

GZ ⊕
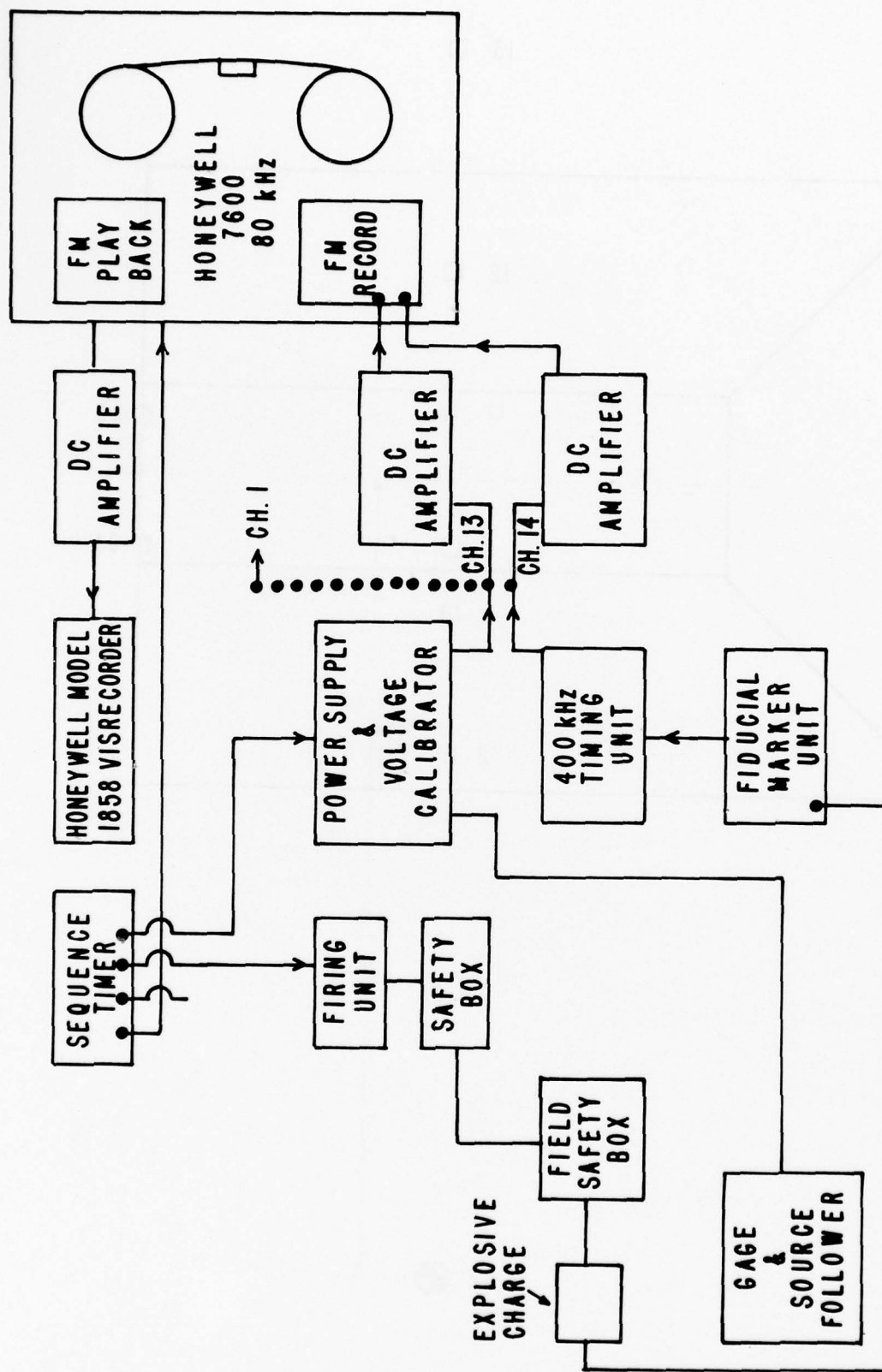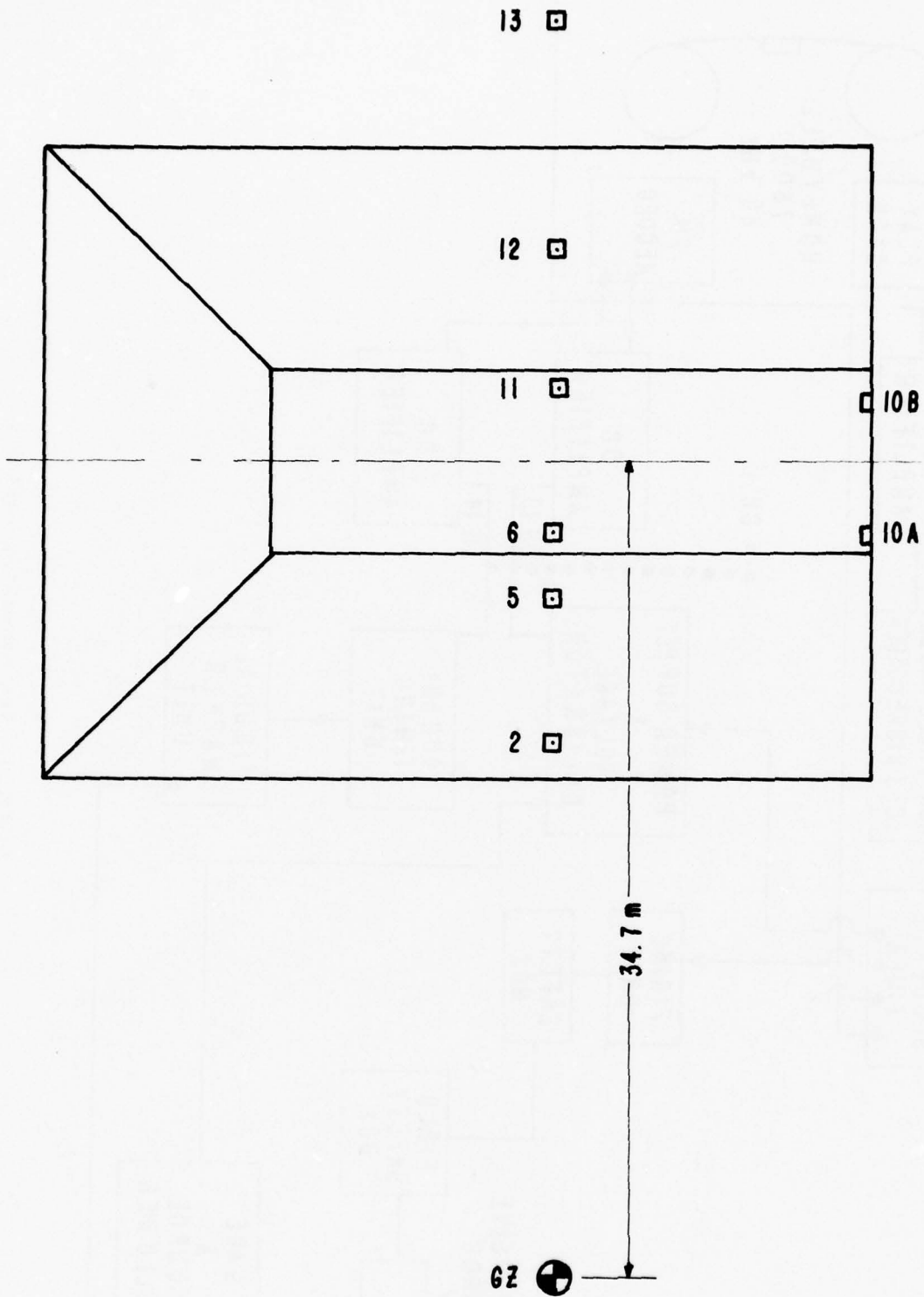
Figure 5. Gage Locations on Full Size Magazine

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Table I. Gage Positions on Full Size Magazine

Position No.	Distance m	Distance ft	Peak Overpressure bar	Peak Overpressure psi	Impulse bar-msec	Impulse psi-msec
2	22.6	74	7.59	110	-	-
			8.28	120	55.4	804
5	28.7	94	-	-	-	-
			11.4	165	45.7	662
6	31.7	104	5.52	80	36.5	529
			6.55	95	55.6	806
11	37.8	124	5.38	78	42.9	622
			5.86	85	44.3	642
12	43.9	144	2.76	40	33.4	484
			-	-	-	-
13	53.0	174	3.45	50	45.0	652
10A	33.8	111	5.17	75	42.5	616
			3.79	55	41.4	600
10B	39.6	130	4.14	60	54.8	795
			2.76	40	40.9	593

NOTE: Position 10A and 10B bracket
Position 10 on the Model Structure.

Distance between center lines of
Donor and Acceptor Magazine is
34.7 metres (114 feet).

First value is from Magazine A
Second value is from Magazine B

bar x 100 = kPa

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taken from the full scale test ESKIMO III report, Reference 3. The
gage locations have been given position numbers to correspond with those
used in the scaled model.

2. Scale Model Magazine. The locations of the gage positions on the
1/30 scale model are shown in Figure 6. Not all positions were instru-
mented on each shot. A maximum of 13 positions and a minimum of 7
positions were instrumented during the series of tests. The relative
positions of the gages remained constant for a particular model scale
but the distance between the charge center and the center line of the
model was varied for each charge weight used.

E. Test Series

There were four series of tests. In series I, II, and III the model
size was held constant while the charge weights were changed. In the
series IV tests the model scale was changed. Each series is described
in the following sections.

1. Test Series I. In test series I a 1/30 scale wooden model was
instrumented as shown in Figure 7. The objective of this test series
was, through the use of a scaled model, to determine the peak overpressure
and impulse that might be expected on a full size storage magazine when
subjected to a 13620 kg (30,000 lb) hemispherical charge of TNT placed
at a distance of 34.7 metres from the centerline. The method used to
determine the scaled distances of the gage positions relative to the
charge center is presented in Table II.

2. Test Series II. In test series II the full size magazine is
assumed to be subjected to the blast load from 27240 kg (60,000 lb) of
TNT. Since the charge weight was doubled then the distance from the
model centerline to the charge center must be increased by $2^{1/3}$ or
1.26. Therefore the 34.74 metres for series I must become 43.77 metres
for series II. The method for calculating the scaled distances for
the increased charge weight is presented in Table III. In test series
II it was desirous to obtain the same peak overpressure but increase
the positive impulse.

3. Test Series III. In test series III the same scaled model 1/30
was used but it was formed with sand. A photograph of the instrumented
model is presented in Figure 8. The record quality improved consider-
ably when the sand model was used. Based on the results from test
series II there was still a need to increase the positive impulse.
Therefore, a charge weight of 34050 kg (75,000 lb) was selected as a
candidate for the full scale test. The procedure as noted in Tables II
and III was used again to determine the scaled distance to place the
small charge. The method is presented in Table IV along with the full

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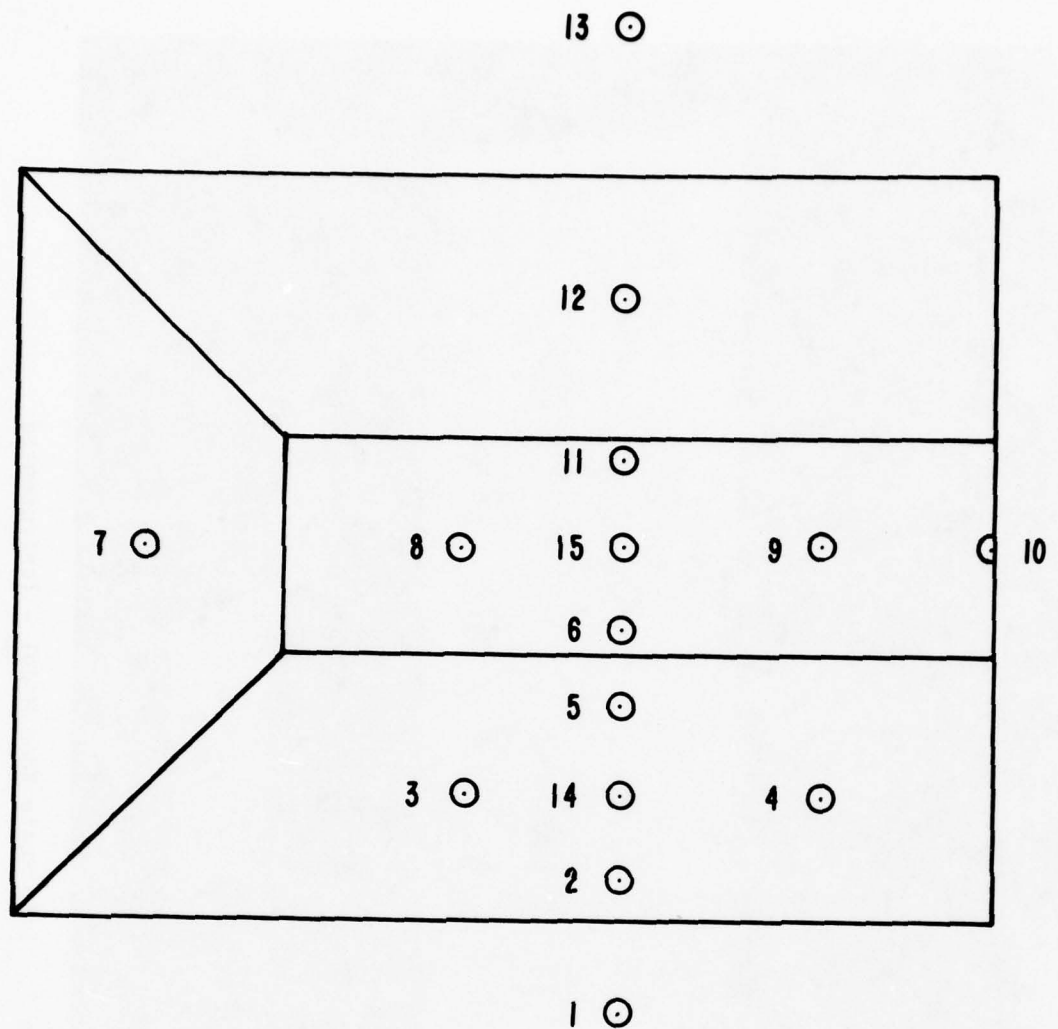
Figure 6. Gage Locations on 1/30 Scale Model Magazine
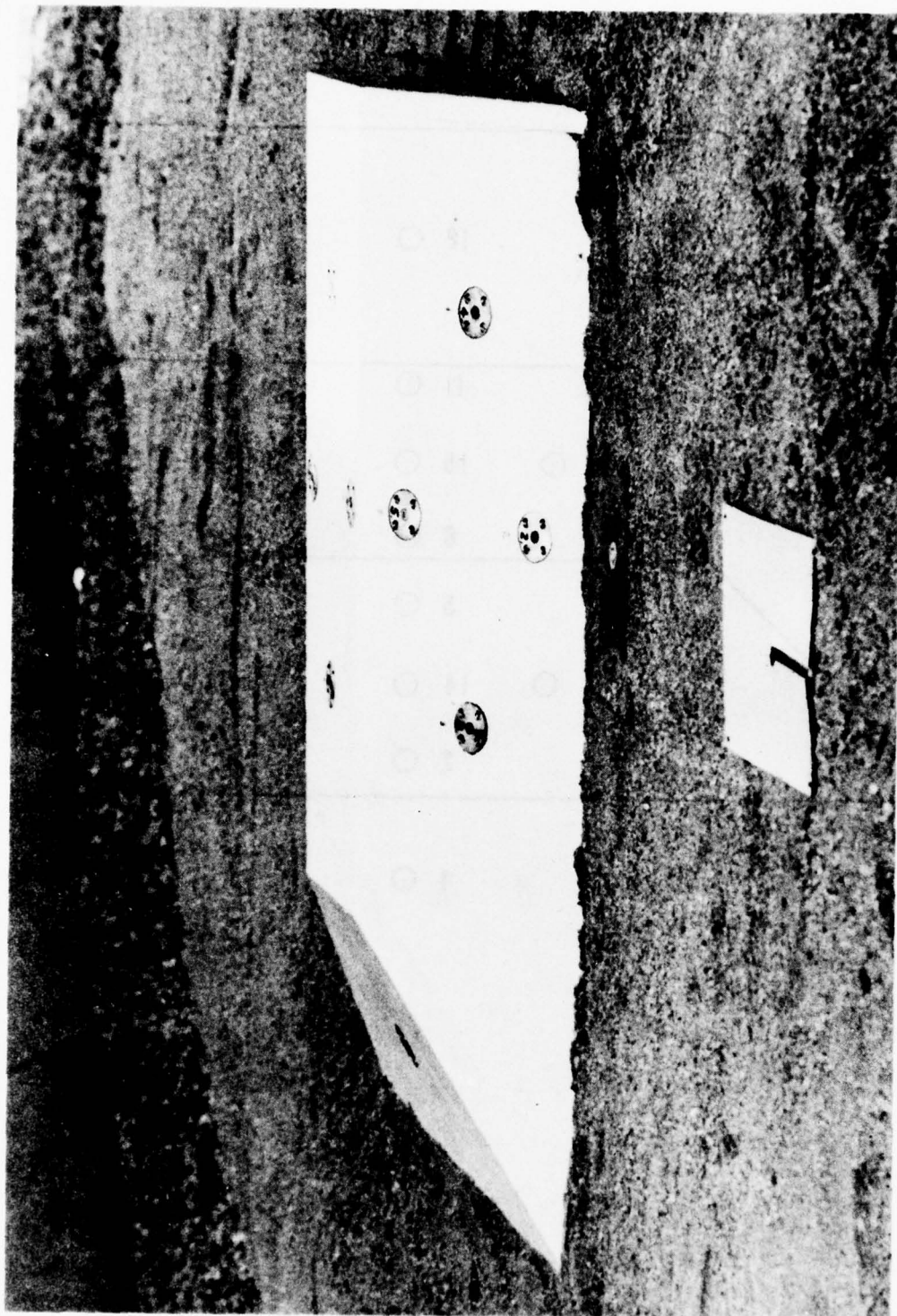
Figure 7. 1/30 Scale Wood Model - Instrumented

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Table II. Gage Distances - Series I Model Tests

Position No.	Full Scale Distance			Scale Distance	
	m	ft		m	ft
1	18.3	60		.62	2.03
2	22.6	74		.77	2.51
3	26.2	86		.89	2.92
4	26.2	86		.89	2.92
5	28.7	94		.97	3.19
6	31.7	104		1.08	3.53
7	38.7	127		1.31	4.31
8	35.4	116		1.20	3.93
9	35.4	116		1.20	3.93
10	36.9	121		1.25	4.10
11	37.8	124		1.28	4.20
12	43.9	144		1.49	4.88
13	53.0	174		1.80	5.90
14	25.6	84		.87	2.85
15*	34.7	114		1.18	3.87

Given: W_2 = 13620 kg (30,000 lb) TNT

R_2 = 34.7m (114 ft)

Determine: Scale distance R_1 for W_1 equal to .531 kg (1.17 lb) TNT.

R_1 = Scale distances from Charge Center to Model Center Line

R_2 = Full scale distance from Charge Center to Magazine Center Line

$$R_1 = R_2 \left(\frac{W_1^{1/3}}{W_2^{1/3}} \right)$$

R_1 = 34.7 (0.03391)

R_1 = 1.18m

NOTE: TNT Equivalency of Pentolite = 1.17

*Center line distance, R_2

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Table III. Gage Distances - Series II Model Tests

Position No.	Full Scale Distances m	ft	Model Scale Distances m	ft
1	27.3	89.6	.93	3.04
2	31.6	103.6	1.07	3.51
3	35.1	115.3	1.19	3.91
4	35.1	115.3	1.19	3.91
5	37.7	123.6	1.28	4.19
6	40.7	133.6	1.38	4.53
7	47.0	154.1	1.59	5.21
8	44.2	145.0	1.50	4.92
9	44.2	145.0	1.50	4.92
10	45.4	149.0	1.54	5.05
11	46.8	153.6	1.59	5.21
12	52.9	173.6	1.79	5.89
13	62.1	203.6	2.10	6.90
14	34.6	113.6	1.17	3.85
15*	43.8	143.6	1.48	4.87

Given: W_2 = 27240 kg (60,000 lb) TNT

R_2 = 43.8 m (143.6 ft)

Determine: R_1, Scale distance for W_1 equal to 1.062 kg (2.34 lb) TNT

R_1 = Scale distance from Charge Center to Model Center Line

R_2 = Full scale distance Charge Center to Magazine Center Line

$$R_1 = R_2 \left(\frac{W_1^{1/3}}{W_2^{1/3}} \right)$$

R_1 = 43.8 (0.03391)

R_1 = 1.48m

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Figure 8. 1/30 Scale Sand Model - Instrumented

Table IV. Gage Distances - Series III Model Tests

Position No.	Full Scale Distances		Model Scale Distances	
	m	ft	m	ft
1	30.7	100.7	1.04	3.41
2	35.0	114.7	1.19	3.89
3	38.5	126.3	1.31	4.28
4	38.5	126.3	1.31	4.28
5	41.1	134.7	1.39	4.57
6	44.1	144.7	1.50	4.91
7	50.1	164.5	1.70	5.58
8	47.5	156.0	1.61	5.29
9	47.5	156.0	1.61	5.29
10	48.8	160.0	1.65	5.43
11	50.2	164.7	1.70	5.59
12	56.3	184.7	1.91	6.26
13	65.4	214.7	2.22	7.28
14	38.0	124.7	1.29	4.23
15	47.2	154.7	1.60	5.25

Given: W_2 = 34050 kg (75,000 lb) TNT
 R_2 = 47.2m (154.7 ft)

Determine: Scale distance R_1, for a W_1 equal to 1.328 kg (2.925 lb) TNT = W_1

R_1 = Scale distance from Charge Center to Model Center Line

R_2 = Full scale distance from Charge Center to Magazine Center Line

$$R_1 = R_2 \left(\frac{W_1^{1/3}}{W_2^{1/3}} \right)$$

$$R_1 = 47.2 \ (0.03391)$$

$$R_1 = 1.60m$$

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and model scale distances.

4. Test Series IV. Although test series III gave the desired
pressure and scaled impulse it was decided to conduct one series with
a smaller model 1/45 and one of the previously used charge weights. A
sand model similar to the one shown in Figure 8 was used on the first
shot and a concrete model as shown in Figure 9 was used for the second
and third shots. The method for calculating the distances from the
charge center to the structure center line of the full scale and model
structure is presented in Table V.

III. RESULTS

The results will be presented primarily in tabular form with
selected overpressure versus time histories to show the loading at
pertinent gauge locations. The major portion of the tests was conducted
using a 1/30 scale model and three different charge weights. Only one
charge weight was fired against the 1/45 scale model. The shot matrix
is presented in Table VI.

A. Scaling Blast Parameters

1. Standard Atmospheric Conditions. The Hopkinson scaling law[5]
was used in this report to design the model test layout, select the
charge weights and predict the blast loading that might be expected on
a full-scale munition magazine. Scaling laws allow the prediction of
blast wave properties from small scale experiments to any other scale,
provided the type of explosive source, the geometry of the source, and
atmospheric conditions are identical.

Theoretically, a target located a distance R_1 from the center
of an explosive source of weight W_1 will be subjected to a blast wave
with a peak overpressure of amplitude P, a duration t_{+1} and a positive
impulse I_1. Now the Hopkinson scaling law states that the distance R_2
at which a target must be placed to receive the same peak overpressure,
from a different charge weight W_2, is a function of the cube roots of
the charge weights. The relationship is given by

$$\frac{R_1}{W_1^{1/3}} = \frac{R_2}{W_2^{1/3}}$$

and

$$R_2 = R_1 \cdot \left(\frac{W_2}{W_1}\right)^{1/3}$$

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[5]B. Hopkinson, British Ordnance Board Minutes 13565, 1915.

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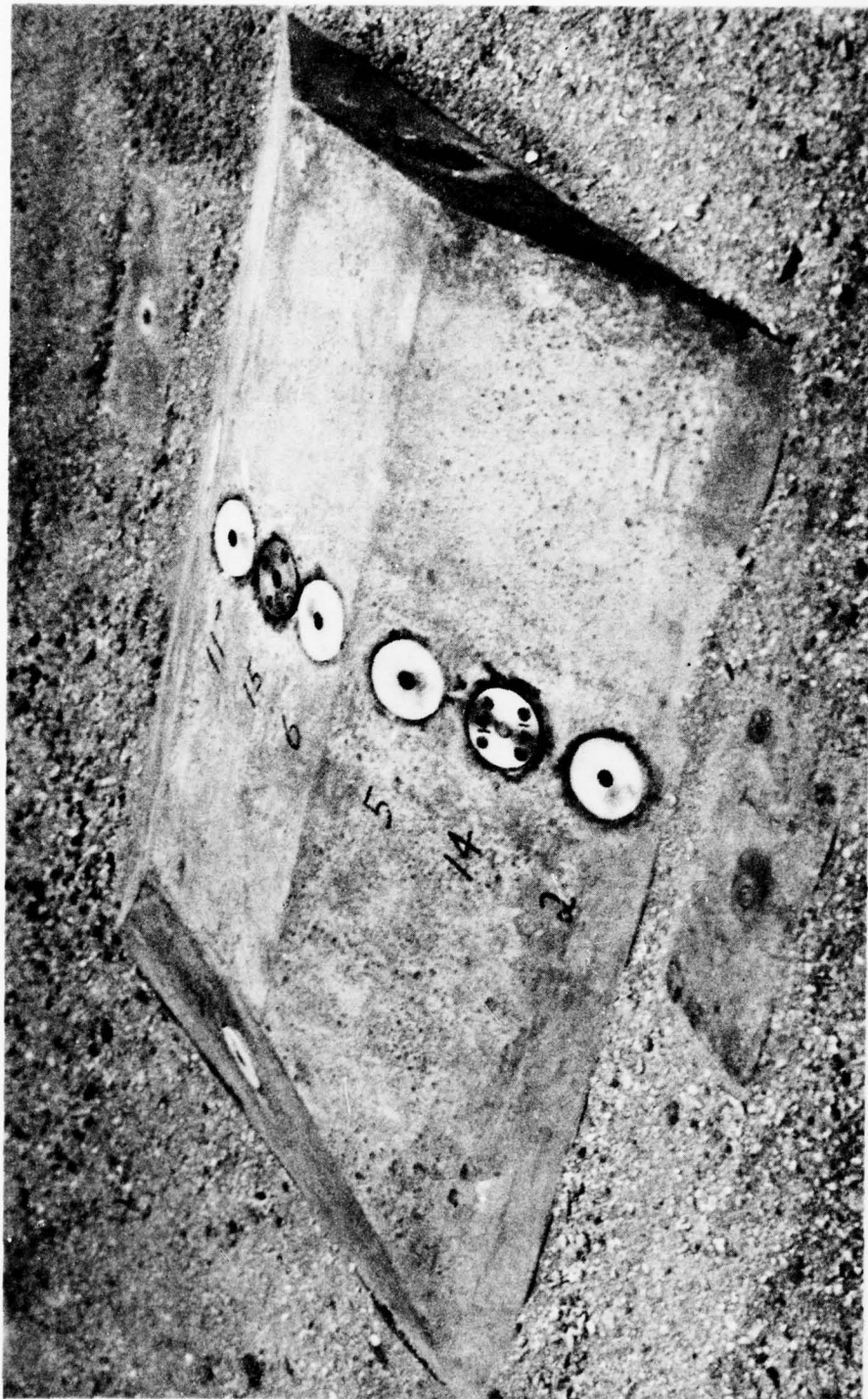
Figure 9. 1/45 Scale Concrete Model - Instrumented

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Table V. Gage Distances - Series IV Model Tests

Position No.	Full Scale Distance		Model Scale Distance	
	m	ft	m	ft
1	33.8	111	.79	2.60
2	38.1	125	.89	2.93
3	41.5	136	.97	3.18
4	41.5	136	.97	3.18
5	44.2	145	1.03	3.39
6	47.2	155	1.11	3.63
7	53.1	174	1.24	4.07
8	50.6	166	1.18	3.89
9	50.6	166	1.18	3.89
10	51.8	170	1.21	3.98
11	53.3	175	1.25	4.10
12	59.4	195	1.39	4.56
13	68.6	225	1.61	5.27
14	41.1	135	.96	3.16
15	50.3	165	1.18	3.86

Given: 41370 kg (91,125 lb) TNT = W_2
   R_2 = 50.3 m (165 ft)

Determine: Scale distance R_1 for W_1 equal to 0.531 kg
   (1.17 lb) TNT

R_1 = Scale distance from Charge Center to Model Center Line

R_2 = Full scale distance from Charge Center to Magazine Center Line

$$R_1 = R_2 \left(\frac{W_1^{1/3}}{W_2^{1/3}} \right)$$

R_1 = 50.3 (.02341)

R_1 = 1.18 m

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Table VI. Test Matrix

Shot	Charge Weights kg	lb	Model Scale	Model Type	Series	Remarks
1	0.449	0.99	1/30	Wood	I	*
2	0.451	0.99	1/30	Wood	I	
3	0.897	1.98	1/30	Wood	II	
4	0.897	1.98	1/30	Wood	II	
5	0.903	1.99	1/30	Wood	II	**
6	0.898	1.98	1/30	Wood	II	
7	0.451	0.99	1/30	Wood	I	
8	0.901	1.98	1/30	Wood	II	
9	0.896	1.97	1/30	Wood	II	
10	0.449	0.99	1/30	Wood	I	
11	0.902	1.99	1/30	Sand	II	
12	0.451	0.99	1/30	Sand	I	
13	0.452	0.99	1/45	Sand	IV	
14	1.135	2.50	1/30	Sand	III	
15	1.134	2.50	1/30	Sand	III	
16	1.125	2.48	1/30	Sand	III	
17	1.136	2.50	1/30	Sand	III	
18	0.447	0.98	1/45	Concrete	IV	
19	0.448	0.99	1/45	Concrete	IV	

AVERAGE WEIGHTS

1/30 Model 2w, 7w, 10w, 12S	- 0.451 kg (0.99 lb)
1/30 Model 3w, 4w, 6w, 8w, 9w, 11	- 0.899 kg (1.98 lb)
1/30 Model 14s, 15s, 16s, 17s	- 1.133 kg (2.50 lb)
1/45 Model 13s, 18c, 19c	- 0.449 kg (0.99 lb)

*Shot 1 - Data not usable

**Shot 5 - Misfire

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For similar conditions then

$$\text{Impulse } I_2 = I_1 \left(\frac{W_2}{W_1}\right)^{1/3}$$

and

$$\text{Duration } t_{+2} = t_{+1} \left(\frac{W_2}{W_1}\right)^{1/3}.$$

Note that the scaling factor required to scale the 1/30 model results to the full size structure is $(W_2/W_1)^{1/3}$ or 29.49. Results from the 1/45 scale model must be scaled by a factor of 42.72.

2. <u>Altitude Corrections</u>. When blast parameters are scaled from standard sea level conditions to altitudes where the ambient atmospheric conditions are appreciably different then corrections must be made[6]. The correction for overpressure is

$$p_a = p_o \left(\frac{P_a}{P_o}\right)$$

where p_a = overpressure at altitude

p_o = overpressure at sea level

P_a = ambient pressure at altitude

P_o = ambient pressure at sea level.

The corrected value for distance (R) for the new overpressure level is given by

$$R_a = R_o \left(\frac{W_2}{W_1}\right)^{1/3} \left(\frac{P_o}{P_a}\right)^{1/3}$$

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[6]R. G. Sachs, "The Dependence of Blast on Ambient Pressure and Tempera-ture," BRL Report No. 466, Aberdeen Proving Ground, Md. 1944. (AD #ATI 39393)

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where

R_a = distance at altitude

R_o = distance at sea level

W_2 = charge weight - full scale

W_1 = charge weight - model scale.

For impulse at altitude, the relationship is

$$I_a = I_o \left(\frac{W_2}{W_1}\right)^{1/3} \left(\frac{P_a}{P_o}\right)^{2/3} \left(\frac{T_o}{T_a}\right)^{1/2}$$

where

T_a = temperature at altitude - degrees K

T_o = temperature at sea level - degrees K.

B. Blast Loading on a 1/30 Scale Model Magazine

The dimensions of the 1/30 scale model magazine are shown in Figure 2. The locations of the airblast gages are shown in Figure 6 with their distances from ground zero or charge center given in Tables II, III, and IV.

1. __Charge Weight 0.454 kg (1 lb) Pentolite.__ In planning the test layout the pentolite charge was assumed to represent 1.17 that amount of TNT. Therefore, in the scaling relationship W_1 was equal to 0.531 kg (1.17 lb) TNT. The tests conducted with this scale model and charge weight are noted in Table II as Series I Model Tests. Although the model was constructed with 1-inch thick plywood and heavy internal bracing the results were disappointing. Some gage positions received excessive accelerations which were superimposed on the record of over-pressure versus time. During this series Positions 3, 4, 8 and 9 were removed and Positions 14 and 15 were added. (See Figure 6).

On shot 12 a 1/30 scale sand model was instrumented and tested. Positions 1, 7, 8, 10, 12, 13, 14, and 15 were instrumented as shown in Figure 8. The results from the sand model were excellent and all but two of the following shots were conducted with sand models.

The records of pressure versus time for each position were tabulated at equal time increments and an average overpressure versus time established. These averages for each position are listed in Table VII.

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Table VII.   Average Overpressure (psi) versus Time (msec) - Series I

Position	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Time msec															
.00	284	335	248	216	177	97	44	63	63	37	59	24	29	245	76
.05	121	215	160	170	124	45	30	55	57	27/46	48	20	23	215	54
.10	68	121	140	70	87	28	25	45	40	36	38	18	20	130	43
.15	43	84	80	50	62	27	26	33	30	30	32	15	17	85	34
.20	31	73	60	35	41	9	16	30	25	22	28	13	15	55	26
.25	22	52	50	25	42	7	14	24	20	19	23	12	13	35	17
.30	18	46	40	20	38	5	13	18	15	16	20	10	12	25	14
.35	12	39	40	15	31	5	10	15	12	14	16	9	9.4	20	13
.40	9	30	25	10	26	6	10	11	10	11	13	9	8.0	20	8.9
.45	10	34	15	8	24	3	9	8	9	10	10	8	7.1	17	9.0
.50	5	38	5	5	22	4	8	6	7	8	7	7	6.1	12	10
.60	0	20	0	0	21	0	5	3	5	5	5	5	4.5	8	6.6
.70		2			14		4	2	4	3	3	4	3.8	5	3.0
.80		0			12		3	0	4	2	2	3	3.3	0	3.0
.90					7		2		3	2	0	1	3.6		2.0
1.0					0		1		0	0		1	2.9		1.0
1.1							0					1	2.3		0
1.2												0	1.4		
1.3													1.1		
1.4													.6		
1.5													.4		
1.6													.2		
1.7													0		
1.8															
	***	***	*	*	***	**	**	**	*	**	***	*	***	*	***

The * indicates the number of acceptable records used in the averaging process.

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From the average overpressure versus time tabulations, impulse versus time was calculated and these calculations are listed in Table VIII. At the bottom of each column the total impulse is noted. The total impulse values from the model were scaled up to full size and are also listed in Table VIII. The gage calibrations are for pounds per square inch (psi) and therefore the listings in Table VII and VIII are overpressure in psi and impulse in psi - msec.

The results from the Series I tests are summarized in Table IX where the pressure and impulse values are listed in both psi, bar and psi-msec, bar-msec. The values listed in Table IX are presented in Figure 10 to show the peak overpressure (bars) and impulse (bar-msec) distribution of the various positions over the full scale munition storage magazine exposed to a 13620 kg (30,000 lb) hemispherical TNT charge.

The peak overpressure recorded at Position 15 was satisfactory but the overpressure impulse was too low, 30.9 bar-msec vs the required 44.8 bar-msec. Therefore, the charge weight was doubled and another test series was conducted.

2. Charge Weight 0.908 kg (2 lb) Pentolite. These tests are designated as Series II and in Table III it is noted that the pentolite charge is assumed to represent 1.062 kg (2.34 lb) TNT. A 1/30 scale model was instrumented and as noted in Series I not all gage positions were instrumented on all shots. Average values of the overpressure versus time recorded at the various positions are listed in Table X. The average values of overpressure versus time were used to calculate the impulse versus time at each gage position. The impulse versus time calculations are listed in Table XI and the total impulse is listed at the bottom of each column for the scale model with a second value for the impulse to be expected on the full size magazine. The peak over-pressure and total positive impulse values from Series II are listed in Table IX. The values listed in Table IX are presented in Figure 11 to show the pressure and impulse distribution to be expected over a full scale munition storage magazine exposed to a 27240 kg (60,000 lb) hemi-spherical TNT charge.

The peak overpressure meets the established criterion but again the overpressure impulse is too low - 41.2 bar-msec versus 44.8 bar-msec. The charge weight was increased 2.5 times the series 1 charge weight and a third test series was conducted.

3. Charge Weight 1.135 kg (2.5 lb) Pentolite. These tests were designated as Series III and in Table IV it is noted that the pentolite charge is assumed to represent 1.328 kg (2.927 lb) of TNT. A 1/30 scale sand model was used for Shots 14, 15, 16, and 17. The instrumented positions are given in Table XII where the average values of over-pressure versus time are listed. The average values of overpressure versus time were used to calculate impulse versus time at each gage

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Table VIII. Average Impulse (psi-msec) versus Time (msec) - Series 1

Position	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Time msec															
.00															
.05	10.1	12.1	8.70	9.65	7.53	3.55	1.85	2.95	2.43	1.41	2.68	1.10	1.30	11.5	3.25
.10	4.73	8.40	7.50	6.00	5.28	1.83	1.38	2.50	2.43	1.78	2.15	.95	1.08	6.63	2.43
.15	2.78	5.13	5.50	3.00	3.73	1.38	1.28	1.95	1.75	1.65	1.75	.83	.93	5.38	1.93
.20	1.85	3.93	3.50	2.13	2.60	.90	1.05	1.58	1.38	1.30	1.50	.70	.80	3.50	1.50
.25	1.33	3.13	2.75	1.50	2.10	.40	.75	1.35	1.13	1.03	1.28	.63	.70	2.25	1.08
.30	1.00	2.45	2.25	1.13	2.00	.30	.68	1.05	.88	.88	1.08	.55	.63	1.50	.78
.35	.75	1.80	2.00	.88	1.73	.25	.58	.83	.68	.75	.90	.48	.54	1.13	.68
.40	.35	1.40	1.63	.63	1.43	.28	.50	.65	.55	.63	.73	.46	.44	1.00	.55
.45	.48	1.60	1.00	.45	1.25	.23	.48	.48	.48	.53	.58	.43	.38	.93	.45
.50	.38	1.80	.50	.33	1.15	.18	.40	.35	.40	.45	.43	.37	.33	.73	.48
.60	.25	2.90	.13	00	1.05	.20	.60	.45	.60	.65	.60	.58	.53	1.00	.83
.70	00	1.10	00		1.75	00	.45	.25	.45	.40	.40	.45	.42	.65	.48
.80		.10			1.30		.35	.10	.40	.27	.25	.35	.36	.25	.30
.90		00			.95		.25	00	.30	.22	.10	.21	.33	00	.25
1.0					.55		.15		.15	.10	00	.14	.26		.15
1.1					00		00			00		.11	.19		.05
1.2												.04	.15		00
1.3												00	.09		
1.4													.05		
1.5													.03		
1.6													.01		
1.7															
1.8															
Model	24.18	45.84	35.46	25.70	34.40	9.50	10.75	14.49	14.01	12.05	14.45	8.58	9.88	36.45	15.19
Full Scale	713	1352	1046	758	1014	280	317	427	415	355	426	247	291	1074	418

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Table IX. Summary of Results on 1/30 Scale Model Magazine

Position	Series I Peak Overpressure psi	bar	Series I Total Impulse psi-msec	bar-msec	Series II Peak Overpressure psi	bar	Series II Total Impulse psi-msec	bar-msec	Series III Peak Overpressure psi	bar	Series III Total Impulse psi-msec	bar-msec
1	284	19.6	713	49.2	214	14.8	1158	79.9	181	12.5	962	66.3
2	335	23.3	1352	93.2	293	20.2	1864	128.5	260*	17.9*	1450*	100*
3	248	17.1	1046	72.1	224	15.4	1053	72.6	-	-	-	-
4	216	14.9	758	52.3	211	14.6	944	65.1	-	-	-	-
5	177	12.2	1014	69.9	167	11.5	1205	83.1	160*	11.0*	1088*	75.0*
6	97	6.69	280	19.3	101	6.97	241	16.6	92	6.34	360	24.8
7	44	3.03	317	21.9	58	4.00	447	30.8	62	4.28	601	41.4
8	63	4.34	427	29.5	69	4.76	447	30.8	78	5.38	624	43.0
9	63	4.34	413	28.5	80	5.52	546	37.7	-	-	-	-
10	46	3.17	355	24.5	39	2.69	494	34.1	60	4.14	585	40.3
11	59	4.07	426	29.4	67	4.62	474	32.7	67	4.62	587	40.1
12	24	1.66	247	17.0	29	2.00	402	27.7	34	2.34	522	36.0
13	29	2.00	291	20.1	36	2.48	428	29.5	37	2.55	386	26.6
14	245	16.9	1074	74.1	212	14.6	1119	77.2	211	14.6	1233	85.0
15	76	5.24	448	30.9	76	5.24	598	41.2	87	6.00	661	45.6

W_2 = 13620 kg (30,000 lbs) W_2 = 27240 kg (60,000 lbs) W_2 = 34050 kg (75,000 lbs)

*Extrapolated values.

PEAK OVERPRESSURE   bar

⊙ 2.0

⊙ 1.66

⊙ 4.07

⊙ 3.03   ⊙ 4.34 ⊙ 5.24   ⊙ 4.34   ▢ 2.55/3.17

⊙ 6.69

⊙ 12.2

⊙ 17.1 ⊙ 16.9   ⊙ 14.9

⊙ 23.4

⊙ 19.6

IMPULSE   bar-ms

⊙ 20.1

⊙ 17.0

⊙ 29.4

⊙ 21.9   ⊙ 29.5 ⊙ 30.9   ⊙ 28.5   ▢ 24.5

⊙ 19.3

⊙ 69.9

⊙ 72.1 ⊙ 74.1   ⊙ 52.3

⊙ 93.2

⊙ 49.2
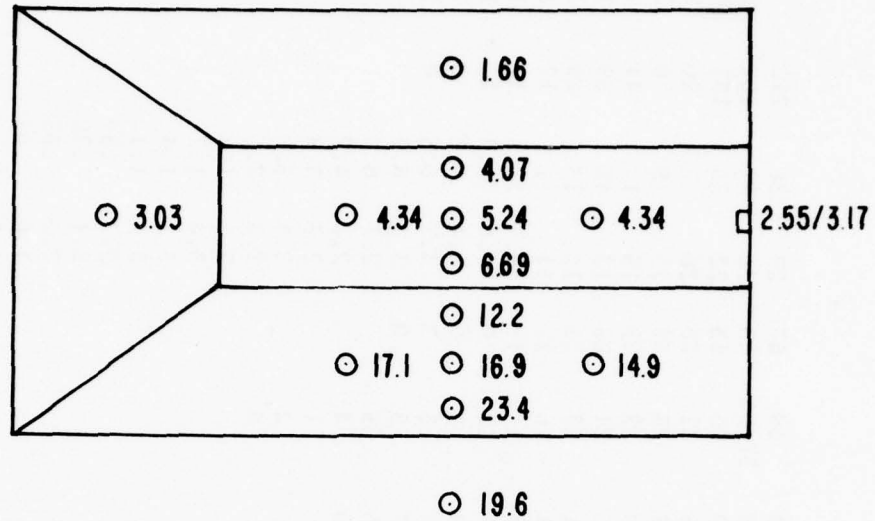
Figure 10. Pressure and Impulse Distribution on Full
Scale Magazine - Series I

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Table X. Average Overpressure (psi) versus Time (msec) - Series II

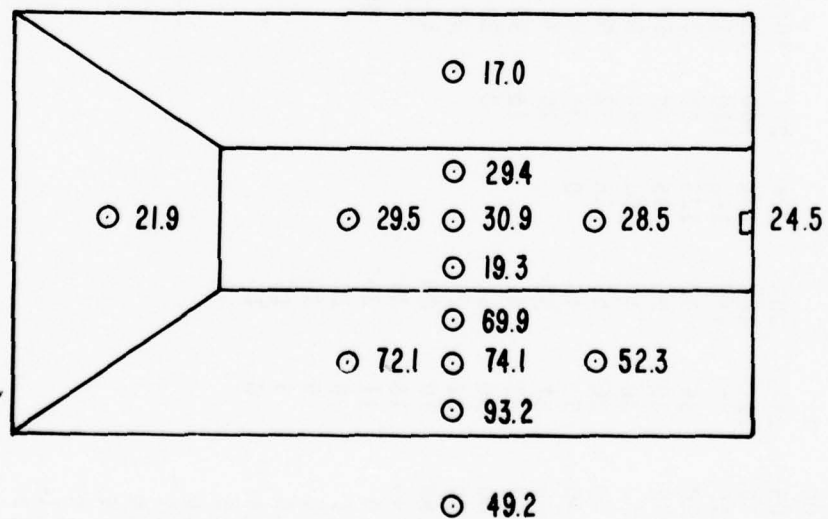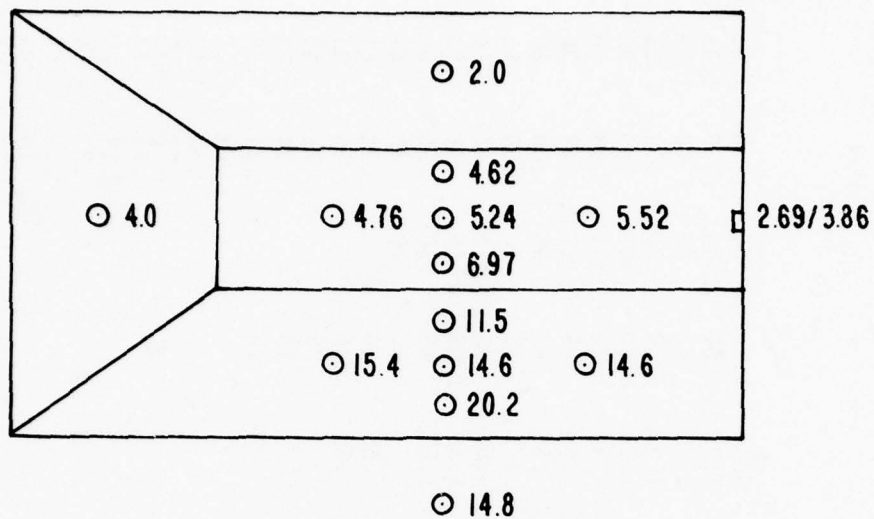| Time Msec	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
.00															
.05	214	293	224	211	167	101	58	69	80	39	67	29	36	212	76
.10	121	187	139	160	135	37	40	52	59	37/56	53	26	29	182	57
.15	77	117	155	110	111	24	28	39	50	36	43	22	25	132	49
.20	55	92	123	61	75	22	23	31	38	31	36	20	22	96	39
.25	40	93	95	58	58	18	21	24	23	25	32	17	19	70	25
.30	30	49	64	42	55	12	19	17	19	23	29	15	17	41	19
.35	26	63	26	32	50	0	17	13	13	21	25	12	15	39	17
.40	31	45	0	31	42		15	8	11	17	21	13	13	29	19
.45	31	52		24	37		15	11	11	16	17	11	11	17	17
.50	34	41		16	33		13	10	18	14	12	9.0	10	13	17
.60	36	31		0	28		10	10	14	12	9	7.8	9.2	12	15
.70	22	24			20		9	5	13	9	6	6.4	7.3	8	13
.80	19	30			13		8	4	8	8	3	4.7	6.8	0	10
.90	13	25			7		7	6	7	5	0	3.3	6.2		5
1.0	11	20			8		5	6	6	5		2.3	6.0		4
1.1	6	24			0		3	3	6	4		2.2	4.7		3
1.2	5	19					2	0	0	1		2.3	3.8		3
1.3	3	15					0			2		2.4	3.0		5
1.4	0	10								0		2.3	2.3		0
1.5		0										3.5	1.8		
1.6												3.4	1.7		
1.7												3.2	1.4		
1.8												3.4	1.1		
1.9												2.3	.82		
2.0												2.1	.70		
2.1												2.0	.35		
2.2												1.8	.65		
												1.5	0		
												1.0			
												0			

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
	*****	*****	**	**	*****	*****	*****	***** ***	**	*	*****	*	******	*	*

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Table XI. Average Impulse (psi-msec) versus Time (msec) - Series II

Position	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Time Msec															
.00															
.05	8.38	12.0	9.08	9.28	7.55	3.45	2.45	3.03	3.48	1.90	3.00	1.38	1.63	9.85	3.33
.10	4.95	7.50	7.35	6.75	6.15	1.53	1.70	2.28	2.73	2.30	2.40	1.20	1.35	7.85	2.65
.15	3.30	5.23	6.95	4.28	4.65	1.15	1.28	1.75	2.20	1.68	1.98	1.05	1.18	5.70	2.20
.20	2.38	4.63	5.45	2.98	3.34	1.00	1.10	1.38	1.53	1.40	1.70	.93	1.03	4.15	1.60
.25	1.75	3.55	3.98	2.50	2.84	.75	1.00	1.03	1.05	1.20	1.53	.80	.90	2.78	1.10
.30	1.40	2.80	2.25	1.85	2.63	.30	.90	.75	.80	1.10	1.35	.68	.80	2.00	.90
.35	1.43	2.70	.65	1.58	2.30	0	.80	.53	.60	.95	1.15	.63	.70	1.70	.90
.40	1.55	2.43	0	1.38	1.98		.75	.48	.55	.83	.95	.60	.60	1.15	.90
.45	1.63	2.33		1.00	1.75		.70	.53	.73	.75	.73	.50	.53	.75	.85
.50	1.75	1.80		.40	1.53		.58	.50	.80	.65	.43	.42	.48	.63	.80
.60	3.40	2.75		0	2.40		.95	.75	1.35	1.05	.45	.71	.83	1.00	1.40
.70	2.55	2.70			1.65		.85	.45	1.03	.85	.30	.56	.66	.40	1.15
.80	1.60	2.75			.95		.75	.50	.73	.65	.10	.40	.65	0	.75
.90	1.20	2.25			.74		.60	.60	.65	.50	0	.28	.61		.45
1.0	.87	2.20			.40		.40	.45	.30	.46		.23	.54		.35
1.1	.58	2.15					.25	.15	0	.25		.23	.43		.30
1.2	.42	1.70					.10	0		.15		.24	.34		.40
1.3	.15	1.25					0			.10		.24	.27		.25
1.4	0	.50								0		.29	.21		0
1.5		0										.35	.18		
1.6												.33	.16		
1.7												.33	.13		
1.8												.29	.10		
2.0												.22	.08		
2.1												.21	.05		
2.2												.19	.05		
												.17	.03		
												.13	0		
												.05			
												0			
Model	39.29	63.22	35.71	32.00	40.86	8.18	15.16	15.16	18.55	16.76	16.07	13.64	14.52	37.96	20.28
Full Scale	1158	1864	1053	944	1205	241	447	447	546	494	474	402	428	1119	598

PEAK OVERPRESSURE   bar

⊙ 2.48

⊙ 2.0

⊙ 4.62
⊙ 4.0   ⊙ 4.76   ⊙ 5.24   ⊙ 5.52   ▯ 2.69/3.86
⊙ 6.97

⊙ 11.5
⊙ 15.4   ⊙ 14.6   ⊙ 14.6
⊙ 20.2

⊙ 14.8

IMPULSE   bar - ms

⊙ 29.5

⊙ 27.7

⊙ 32.7
⊙ 30.8   ⊙ 30.8   ⊙ 40.2   ⊙ 37.7   ▯ 34.1
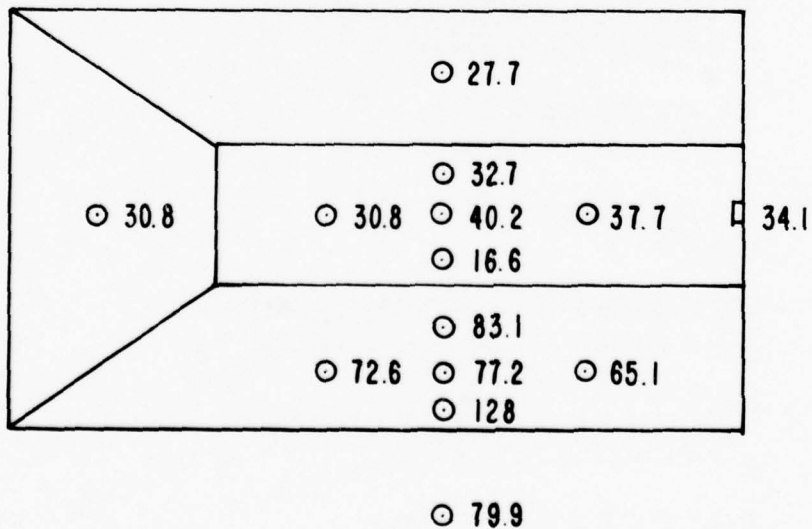⊙ 16.6

⊙ 83.1
⊙ 72.6   ⊙ 77.2   ⊙ 65.1
⊙ 128

⊙ 79.9

Figure 11.   Pressure and Impulse Distribution on
Full Scale Magazine - Series II

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Table XII. Average Overpressure (psi) versus Time (msec) Series III

Position	1	6	7	8	10	11	12	13	14	15
Time msec										
.00	181	71	62	78	42	67	34	37	211	87
.05	118	53/92	45	62	38/60	55	28	31	165	70
.10	78	31	36	53	43	44	25	26	132	53
.15	60	26	32	47	33	43	23	23	100	43
.20	42	19	28	35	29	31	19	20	73	32
.25	33	17	22	27	27	33	18	18	51	27
.30	32	14	22	23	22	29	16	16	38	22
.35	28	9.5	19	20	20	23	15	13	28	18
.40	20	4.7	16	18	19	22	13	11	23	16
.45	22	5.0	16	15	16	20	12	8.7	20	15
.50	17	3.6	12	13	14	17	11	7.7	16	13
.60	12	2.6	11	10	13	11	8.8	6.5	13	10
.70	9.0	0	9.6	8.4	8.7	5.5	7.1	5.0	11	8.9
.80	8.0		7.8	6.6	6.3	2.8	5.5	3.6	7.3	8.4
.90	6.3		6.4	3.3	5.5	0	5.0	4.8	4.5	6.4
1.0	4.5		4.4	2.1	4.1		3.2	3.5	3.3	4.7
1.1	3.8		2.9	1.0	3.6		3.6	2.5	.50	3.2
1.2	2.0		2.7	.5	3.3		5.1	1.7	0	1.5
1.3	1.8		2.7	0	2.2		4.8	1.1		.80
1.4	2.0		4.9		1.0		4.9	.80		0
1.5	1.0		3.3		.10		4.7	.58		
1.6	.75		1.4		.50		4.3	.87		
1.7	.25		1.5		0		3.8	.87		
1.8	.13		2.2				3.5	.25		
1.9	0		0				3.2	0		
2.0							2.6			
2.1							1.9			
2.2							1.3			
2.3							1.1			
2.4							.5			
2.5							.5			
2.6							0			
	****	*	***	***	****	*	****	****	****	***

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position. The impulse versus time calculation are listed in Table XIII
with the total impulse noted at the bottom of each column. The peak
overpressure and total positive impulse values from Series III are
listed in Table IX. They are presented in Figure 12 to show the pres-
sure and impulse distribution to be expected over a full scale munition
storage magazine exposed to a 34,050 kg (75,000 lb) hemispherical charge
of TNT.

On test series III the peak overpressure criterion was satisfied
at Position 15 with 6.0 bars (87.0 psi). The requirement was from 5.37
to 6.55 bars (78 - 95 psi). The overpressure impulse requirement was
44.8 bars (650 psi-msec) and at Position 15 an overpressure impulse of
45.6 bars (661 psi-msec) was obtained. Therefore, a recommendation for
the full scale test was a 34,050 kg (74,000 lb) hemispherical charge of
TNT placed 47.2 m (155 ft) from the center line of the acceptor maga-
zines.

C. Blast Loading on a 1/45 Scale Model Magazine

The dimensions of the 1/45 scale model magazine are shown in Figure
3. A photograph of the instrumented model is presented in Figure 9.
This test series (Series IV) was conducted to determine the blast load-
ing to be expected from a 41,370 kg (91,125 lb) TNT charge placed 50.3 m
(165 ft) from the centerline of the full size munition storage magazine.
As noted in Table VI, on Shot 13 a sand model was used while on Shots
18 and 19 a concrete model was used. The gage position and charge
weight are given in Table V.

Values of the average overpressure versus time for the three shots
are listed in Table XIV for all positions instrumented. These average
values of overpressure versus time were used to calculate values of
average impulse versus time which are listed in Table XV. The total
positive impulse for each position is listed at the bottom of each
column. The second value in the column is the scaled up value of total
impulse to be expected at the same location on a full size structure.

The distribution of peak overpressure and impulse to be expected
over a full size magazine is shown in Figure 13.

Although the full-scale charge weight for Test Series IV would be
approximately 22 percent greater than the 34050 kg (75,000 lb) con-
sidered for Test Series III, there was very little difference in the
scaled up overpressure impulse values on the top of the structure.
Compare the overpressure impulse values presented in Figure 12 versus
Figure 13.

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Table XIII. Average Impulse (psi-msec) versus
Time (msec) - Series III

Position	1	6	7	8	10	11	12	13	14	15
Time-msec										
.00										
.05	7.48	3.10	2.68	3.50	2.00	3.05	1.55	1.70	9.40	3.93
.10	4.91	3.08	2.03	2.88	2.58	2.48	1.33	1.43	7.43	3.08
.15	3.44	1.42	1.70	2.50	1.90	2.18	1.20	1.23	5.80	2.40
.20	2.54	1.11	1.50	2.05	1.55	1.85	1.05	1.08	4.33	1.88
.25	1.88	.91	1.25	1.55	1.40	1.60	.93	.95	3.10	1.48
.30	1.64	.78	1.10	1.25	1.23	1.55	.85	.85	2.23	1.23
.35	1.49	.56	1.03	1.08	1.05	1.30	.78	.73	1.65	1.00
.40	1.19	.36	.88	.95	.98	1.13	.70	.60	1.28	.85
.45	1.04	.24	.80	.83	.88	1.05	.63	.49	1.08	.78
.50	.98	.22	.70	.70	.75	.93	.58	.41	.90	.70
.60	1.48	.31	1.15	1.15	1.35	1.40	.99	.71	1.45	1.15
.70	1.06	.13	1.03	.92	1.09	.83	.80	.58	1.20	.95
.80	.85	0	.87	.75	.75	.42	.63	.43	.92	.87
.90	.71		.71	.50	.55	.14	.53	.42	.59	.74
1.00	.54		.54	.27	.48	0	.41	.42	.39	.56
1.1	.41		.37	.16	.39		.34	.30	.04	.40
1.2	.30		.28	.08	.35		.44	.21	.03	.24
1.3	.20		.27	.03	.28		.50	.14	0	.12
1.4	.19		.38	0	.16		.49	.10		.04
1.5	.15		.41		.06		.48	.07		0
1.6	.09		.24		.03		.45	.07		
1.7	.05		.15		.03		.41	.09		
1.8	.02		.19		0		.37	.06		
1.9	0		.11				.34	.02		
2.0			0				.29	0		
2.1							.23			
2.2							.16			
2.3							.12			
2.4							.08			
2.5							.05			
2.6							0			
Model	32.64	12.22	20.37	21.15	19.84	19.91	17.71	13.09	41.82	22.4
Full Scale	962	360	601	624	585	587	522	386	1233	661

41

PEAK OVERPRESSURE   bar

⊙ 2.55

⊙ 2.34

⊙ 4.62
⊙ 4.28   ⊙ 5.38 ⊙ 6.00   ▯ 4.14
⊙ 6.34

⊙ 14.6

⊙ 12.5

IMPULSE   bar-ms

⊙ 26.6

⊙ 36.0

⊙ 40.1
⊙ 41.4   ⊙ 43.0 ⊙ 45.6   ▯ 40.3
⊙ 24.8

⊙ 85.0

⊙ 66.3
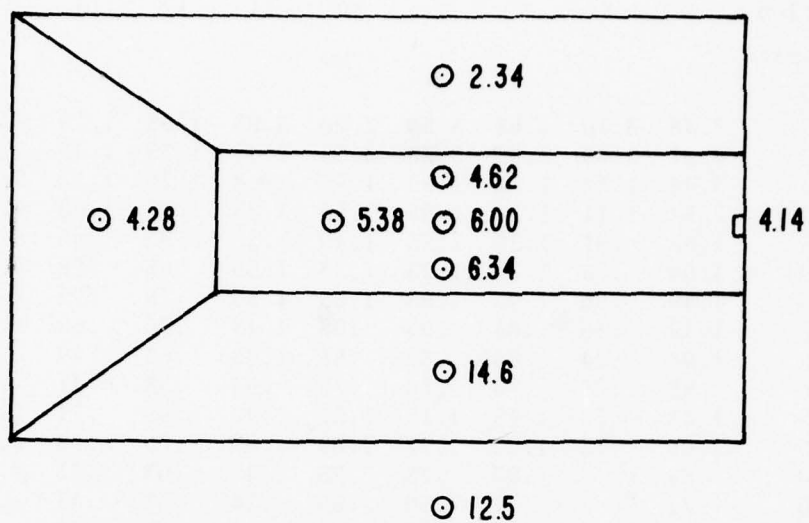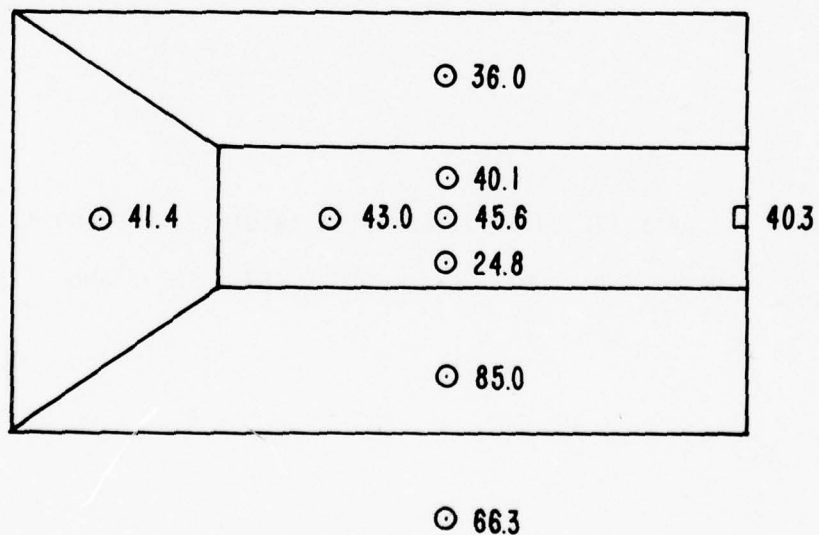
Figure 12.   Pressure and Impulse Distribution on
Full Scale Magazine - Series III

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Table XIV. Average Overpressure (psi) versus Time (msec) - Series IV

Position	1	2	5	6	7	10	11	12	13	14	15
Time msec											
.00	172	347	147	96	57	55	70	31	36	156	81
.05	96	150	103	39	45	48	45	28	29	126	50
.10	61	113	74	25	29	36	42	25	23	96	45
.15	43	72	68	15	24	31	38	20	18	63	36
.20	31	41	50	14	22	26	30	16	15	43	30
.25	24	30	31	9.3	20	21	21	15	12	32	18
.30	23	21	21	3.8	17	18	16	12	11	25	15
.35	26	15	14	4.3	15	18	9.7	9.2	9.4	19	12
.40	16	10	11	3.6	13	14	7.0	7.8	8.6	14	9.5
.45	13	5	11	3.6	11	12	5.3	8.4	8.3	10	7.8
.50	12	3	10	2.8	8.9	8.7	2.9	6.5	8.0	7.3	6.5
.60	8.0	0	8	0	6.5	7.3	2.0	5.3	5.2	6.3	5.7
.70	5.3		0		4.4	4.4	0	5.0	4.2	4.0	6.0
.80	4.0				3.7	3.8		4.0	2.8	2.0	3.5
.90	3.0				3.2	4.1		5.5	2.2	0	3.0
1.0	2.3				1.2	1.3		4.6	1.2		1.5
1.1	0				1.0	1.8		4.2	.6		0
1.2					0	1.8		3.6	.4		
1.3						1.0		3.4	0		
1.4						0		3.0			
1.5								1.8			
1.6								.9			
	***	**	*	*	***	***	*	*	***	**	**

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Table XV. Average Impulse (psi-msec) versus Time (msec) - Series IV

Position	1	2	5	6	7	10	11	12	13	14	15
Time msec											
.00											
.05	6.70	12.4	6.25	3.38	2.55	2.58	2.88	1.48	1.63	7.05	3.28
.10	3.93	6.58	4.43	1.60	1.85	2.10	2.18	1.33	1.30	5.55	2.38
.15	2.60	4.63	3.55	1.00	1.33	1.68	2.00	1.13	1.03	3.98	2.03
.20	1.85	2.83	2.95	.73	1.15	1.43	1.70	.90	.83	2.65	1.65
.25	1.38	1.78	2.03	.58	1.05	1.18	1.28	.78	.68	1.88	1.20
.30	1.17	1.28	1.30	.33	.93	.98	.93	.68	.58	1.43	.83
.35	1.23	.90	.88	.20	.80	.90	.64	.53	.51	1.10	.68
.40	1.05	.63	.63	.20	.70	.80	.42	.43	.45	.83	.54
.45	.73	.38	.55	.18	.60	.65	.31	.41	.42	.60	.43
.50	.63	.20	.53	.16	.50	.52	.21	.37	.41	.43	.36
.60	1.00	.15	.90	.14	.77	.80	.24	.59	.66	.68	.52
.70	.67	0	.40	0	.49	.59	.10	.45	.47	.52	.49
.80	.47		0		.41	.41	0	.48	.35	.30	.48
.90	.35				.35	.40		.51	.25	.10	.33
1.0	.27				.22	.27		.44	.17	0	.23
1.1	.12				.11	.16		.39	.09		.08
1.2	0				.05	.18		.35	.05		0
1.3					0	.14		.32	.02		
1.4						.05		.24	0		
1.5						0		.14			
1.6								.05			
								0			
Model	24.15	31.76	24.40	8.50	13.86	15.82	12.89	12.52	9.90	27.1	15.51
Full Scale	1032	1357	1042	363	592	676	551	535	423	1157	665

44

PEAK OVERPRESSURE   bar

⊙ 2.48

⊙ 2.14

⊙ 4.83
⊙ 5.59   ☐ 3.79
⊙ 6.62

⊙ 3.93

⊙ 10.1
⊙ 10.8
⊙ 23.9

⊙ 11.9
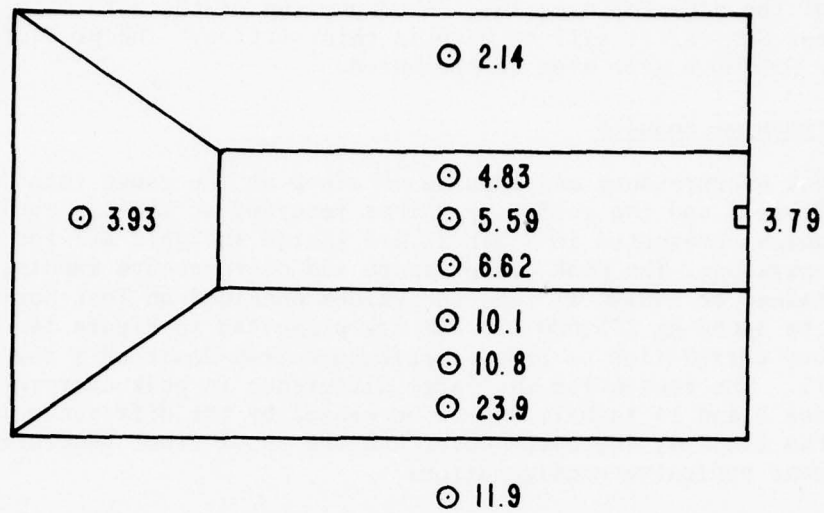
OVERPRESSURE IMPULSE   bar-ms

⊙ 29.2

⊙ 36.9

⊙ 38.0
⊙ 45.7   ☐ 46.6
⊙ 25.0

⊙ 40.8

⊙ 71.9
⊙ 79.8
⊙ 93.6

⊙ 71.1
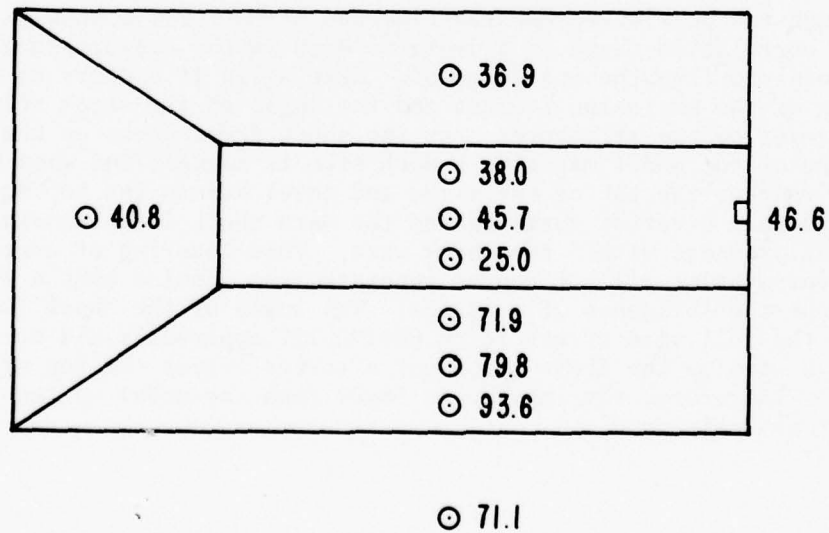
Figure 13.   Pressure and Impulse Distribution on
Full Scale Magazine - Series IV

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IV.   DISCUSSION AND RECOMMENDATIONS

The results from test Series III met the requirement for an impulse load of 44.8 bar-msec (650 psi-msec) on the earth cover at the apex of the arch of the acceptor magazine. A comparison of the data from ESKIMO III and Test Series III will be made in this section. The predicted values for ESKIMO V will also be presented.

A. Comparison of Results

The peak overpressure and impulse obtained at the gauge location shown in Table I and the scaled-up values recorded at similar positions on the model, as presented in Table IX, are listed in Table XVI for a direct comparison. The peak overpressure and overpressure impulse values obtained on ESKIMO III and the values obtained on Test Series III scaled up to 34050 kg (75,000 lb) TNT are presented in Figure 14. There is very good correlation of peak overpressure from Position 5 through Position 13. The reason for the large difference in peak overpressure at Positions 2 and 14 is believed to be caused by the difference in the angle of the slope of the earth cover and the shock front generated from two different explosive configurations.

The covered explosive charge from ESKIMO III would produce a curved shock front propagating downward toward the slope, probably producing a regular reflection at the toe of the slope. The bare hemispherical charge used in Test Series III produces a vertical shock front starting up the toe of the slope which in turn produces a Mach reflection, and a Mach stem moves up the slope.

The overpressure impulse shows the same trend except the model values are higher at all three front slope positions than recorded on the ESKIMO III front slope positions.

Although the peak overpressures recorded at Position 6 show excellent correlation there is a dramatic drop in the overpressure impulse obtained from the scaled model. Here again it appears to be a function of the explosion sources and the angle of the shock relative to earth cover on the structures. As the shock front moves up the front slope of the model magazine a Mach stem is formed; and when the Mach stem reaches the top of the slope and moves across the top surface of the structure a vortex forms behind the Mach shock front causing a lowering of pressure within the shock wave. This lowering of over-pressure versus time will of course generate less impulse than a shock wave without the influence of a vortex. The angle of the shock front impinging the full size structure on ESKIMO III apparently did not form a Mach stem up the front slope nor a vortex across the top of the structure. Therefore, the impulse is lower than the model up the slope and higher at Position 6.

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Table XVI. Comparison of Results from ESKIMO III and Test Series III

Position No.	Peak Overpressure bar		Impulse bar-msec		Peak Overpressure psi		Impulse psi msec	
	ESKIMO III	Model	ESKIMO III	Model	ESKIMO III	Model	ESKIMO III	Model
1	-	12.5	-	66.3	-	181	-	962
2a	7.59	17.9*	-	100*	110	260*	-	1450*
2b	8.28	-	55.4	-	120	-	804	-
14	-	14.6	-	85.0	-	211	-	1233
5a	-	11.0*	-	75.0*	-	160*	-	1088*
5b	11.4	-	45.7	-	165	-	662	-
6a	5.52	6.34	36.5	24.8	80	92	529	360
6b	6.55	-	55.6	-	95	-	806	-
15	-	6.00	-	45.6	-	87	-	661
11a	5.38	4.62	42.9	40.1	78	67	622	587
11b	5.86	-	44.3	-	85	-	642	-
8	-	5.38	-	43.0	-	78	-	624
7	-	4.28	-	41.4	-	62	-	601
10a	4.48	-	41.9	-	65	-	608	-
10	-	4.14	-	40.3	-	60	-	585
10b	3.45	-	47.8	-	50	-	694	-
12a	2.76	2.34	33.4	36.0	40	34	484	552
12b	-	-	-	-	-	-	-	-
13	3.45	2.55	45.0	26.6	50	37	652	386

Designation a and b are for Magazine A and B on ESKIMO III. Values from the model test series III are listed with the a designation.

*Indicates extrapolated values based on other test series.

47
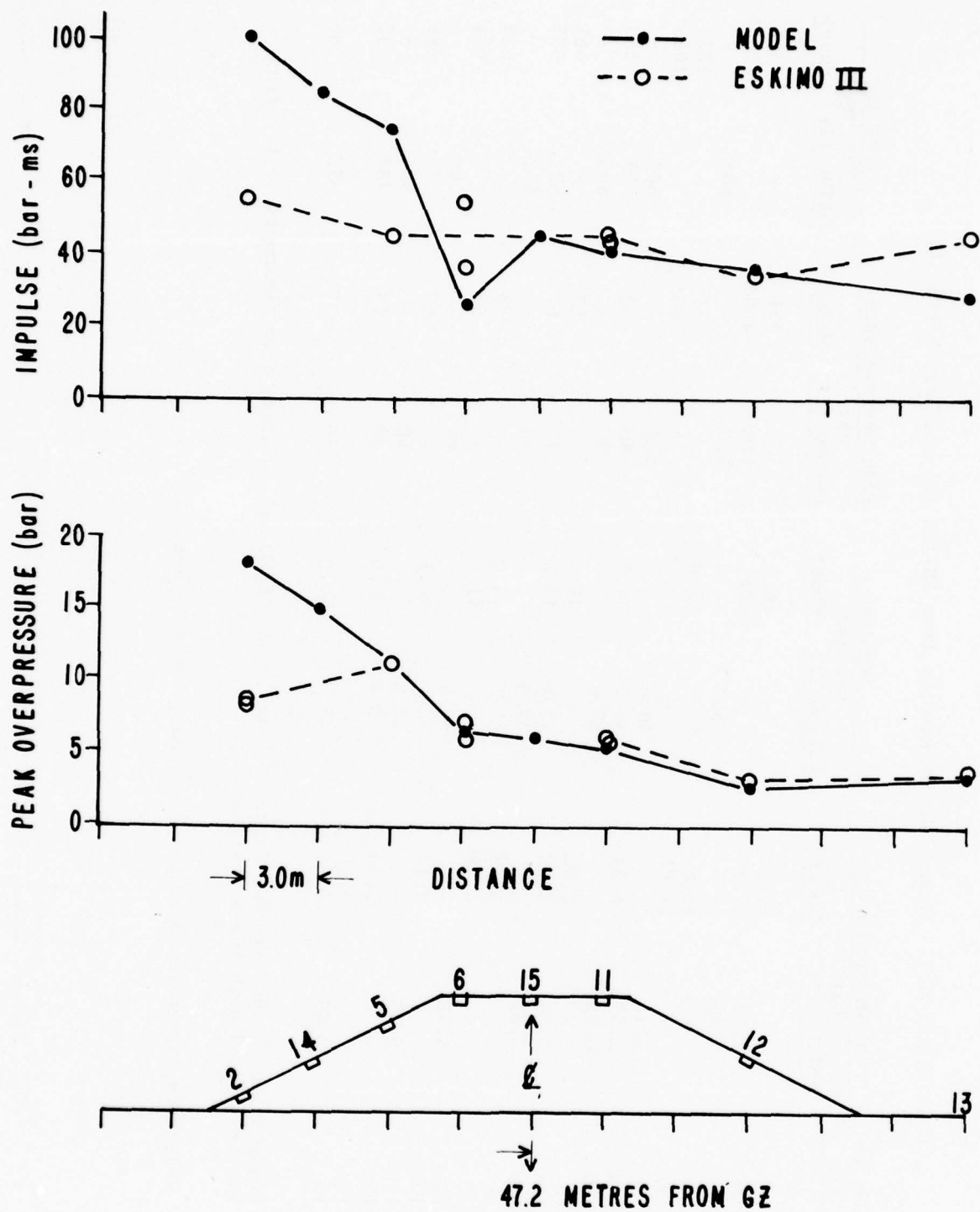
Figure 14. Comparison of Results from ESKIMO III and
Test Series III Scaled to 34050 kg TNT

Other positions show very good correlation of both peak overpressure and overpressure impulse with the exception of position 13 where the impulse from ESKIMO III is higher than recorded on test Series III.

B. Shock Reflection and Diffraction - Theory and Experiment

The theoretical treatment of shock reflection and diffraction presented in this section was taken from Reference 7. It contains a summary of methods for predicting the effects of terrain on blast wave propagation.

1. Mach Reflection Pressure on the Front Slope. The peak Mach reflection overpressure up the center of the front slope of the model structure can be determined from two-dimensional theory. A typical Mach reflection pattern is shown in Figure 15. Here the incident shock pressure ratio Z is P_s/P_o, where P_s is the peak incident overpressure and P_o is atmospheric pressure. The pressure ratio for the Mach reflected shock Z_m is P_M/P_o, where P_m is the peak Mach overpressure and P_o is atmospheric pressure. The angle θ in Figure 15 is 26.6 degrees.

The incident shock pressure ratio Z for a hemispherical pentolite surface burst is plotted versus scaled distance in Figure 16. This curve was developed from data presented in Reference 1. When Z is determined for a selected scaled distance up the front slope then the Mach reflection ratio Z_m can be determined from Figure 17 where Z_m is plotted as a function of Z for a slope angle of 26.6 degrees. This curve was developed from data presented in Reference 7.

The values of Z_m determined up the front slope for selected scaled distances have been plotted in Figure 16 and listed for the gauge positions 2, 14, and 6 in Table XVII. The Mach pressure ratio Z_m values were converted to P_m values for a direct comparison with experimental values of P_m.

2. Shock Diffraction Pressures on the Roof. When a rising slope changes to a falling slope then the Mach reflection process changes to a shock diffraction. The process is reversed and the pressure on the surface becomes less than the input pressure. This condition is shown in Figure 15 where Z_m becomes the input shock ratio and the diffracted shock pressure ratio is noted as Z_T which is P_T/P_o where P_T is the overpressure on the top of the structure and P_o is the atmospheric pressure. A plot of Z_T as a function of Z_m for θ equal to 26.6° is presented in Figure 18. Based on the assumption that the diffraction process is a reversal of the reflection process the overpressure ratio Z_T across the top of the model structure becomes equal to Z, the incident overpressure ratio shown in Figure 16. The values of Z_T, determined from Figure 18 have been plotted

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[7] R. J. Arave and N. R. Wallace, "Dynamic Pressure from Blast Waves: Methods for Predicting the Effects of Terrain," URS Corporation, URS 649-6, February 1966.

49
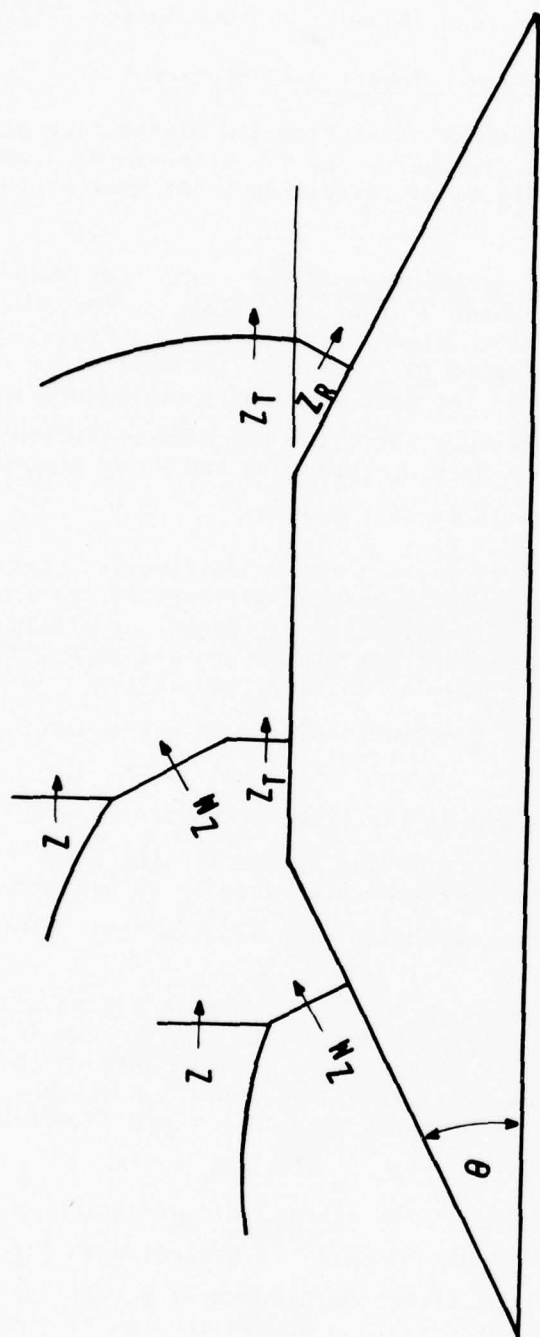
Figure 15. Mach Reflection and Diffraction Pattern
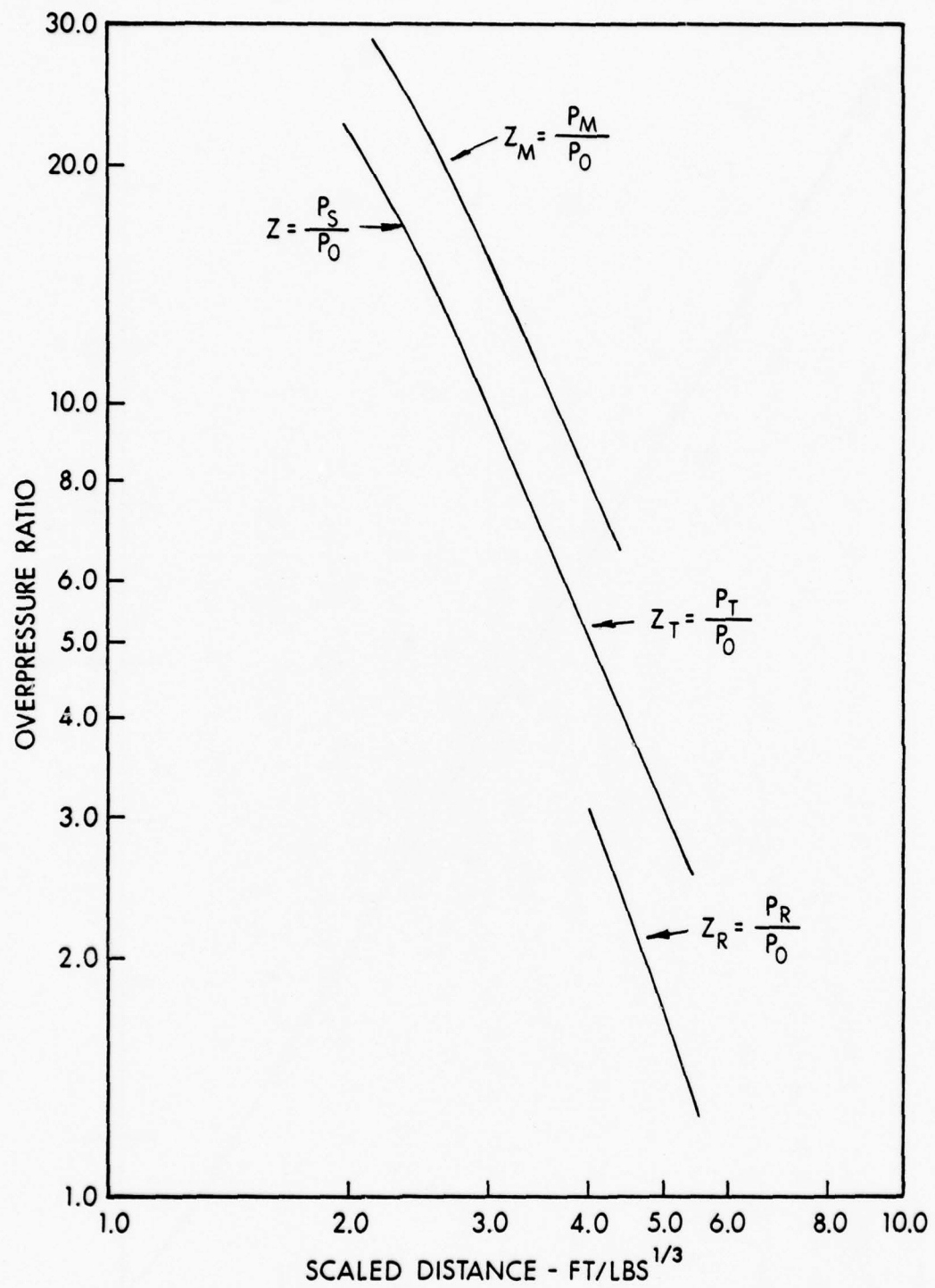
Figure 16. Overpressure Ratio versus Scaled Distance

51
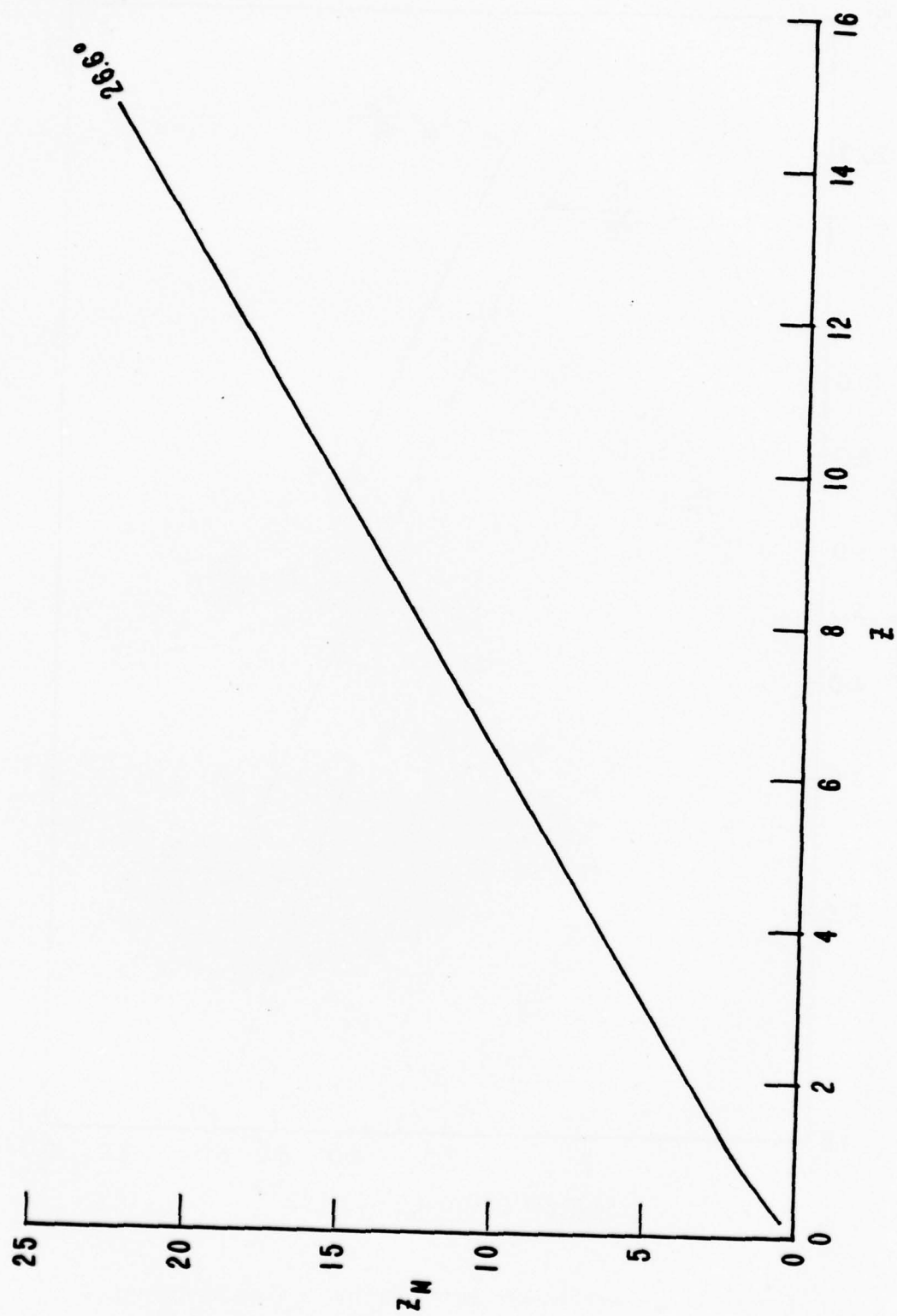
Figure 17. Input Pressure Ratio versus Mach Reflection Pressure Ratio

22.6°

Z_N

Table XVII. Mach Reflection and Diffraction-Theory and Experiment

Series I

Position Number	Scaled Distance λ ft/lbs$^{1/3}$	Z	Z_m	Peak Mach Overpressure Theory psi	Experiment psi
2	2.51	15.0	23.0	338	338
14	2.85	11.4	17.6	259	245
5	3.19	8.7	13.6	199	177
*	3.43	7.3	11.4	168	–

		Z_m	Z_T		
6	3.53	10.8	6.9	100	97
15	3.87	8.9	5.6	82	76
11	4.20	7.4	4.6	67	59
**	4.31	7.0	4.3	63	–

		Z_T	Z_R		
12	4.88	3.2	1.8	27	24

Series II

Position Number	Scaled Distance λ	Z	Z_m	Theory	Experiment
2	2.79	12.0	18.5	272	295
14	3.06	9.6	14.9	219	212
5	3.33	7.8	12.2	179	167
*	3.52	7.0	11.0	162	–

		Z_m	Z_T		
6	3.60	10.4	6.6	97	101
15	3.87	8.9	5.6	82	76
11	4.14	7.6	4.7	69	67
**	4.22	7.3	4.5	66	

		Z_T	Z_R		
12	4.67	3.6	2.1	30	29

Series III

Position Number	Scaled Distance λ ft/lbs$^{1/3}$	Z	Z_m	Peak Mach Overpressure Theory psi	Experiment psi
2	2.87	11.0	17.0	250	260
14	3.12	9.0	14.0	206	211
5	3.37	7.8	12.2	179	160
*	3.55	6.8	10.7	157	-
		Z_m	Z_T		
6	3.62	10.3	6.5	96	92
15	3.87	8.9	5.6	82	87
11	4.12	7.7	4.8	70	67
**	4.19	7.4	4.6	68	-
		Z_T	Z_R		
12	4.61	3.7	2.1	31	34

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Table XVII. Mach Reflection and Diffraction-Theory
and Experiment (Continued)

Series IV

Position Number	Scaled Distance	Z	Z_m	Peak Mach Overpressure	
	λ			Theory	Experiment
	$ft/lbs^{1/3}$			psi	psi
2	2.93	10.6	16.4	241	347
14	3.16	8.9	13.9	203	156
5	3.39	7.6	11.9	175	147
*	3.43	7.3	11.4	168	-
		Z_m	Z_T		
6	3.63	10.0	6.3	93	96
15	3.87	8.9	5.6	82	81
11	4.10	7.8	4.9	71	70
**	4.31	7.0	4.3	63	-
		Z_T	Z_R		
13	4.56	3.9	2.3	33	31

*Top of front slope.

**Rear edge of roof.

NOTE: WHERE:

$Z = P_s/P_o$ P_s = Peak incident overpressure

$Z_m = P_m/P_o$ P_m = Peak mach overpressure

$Z_T = P_T/P_o$ P_T = Peak overpressure on top
                                                     of structure

$Z_R = P_R/P_o$. P_R = Peak overpressure on rear
                                                     slope

                                               P_o = Atmospheric pressure.

55

$$Z_R = \frac{Z_T - 0.5}{1.5} \quad Z_T > 2$$

$$Z_T = \frac{Z_M - 0.5}{1.5} \quad Z_M > 2$$

26.9°

Z_M or Z_T

Z_T or Z_R

0   2   4   6   8   10   12   14   16

0   2   4   6   8
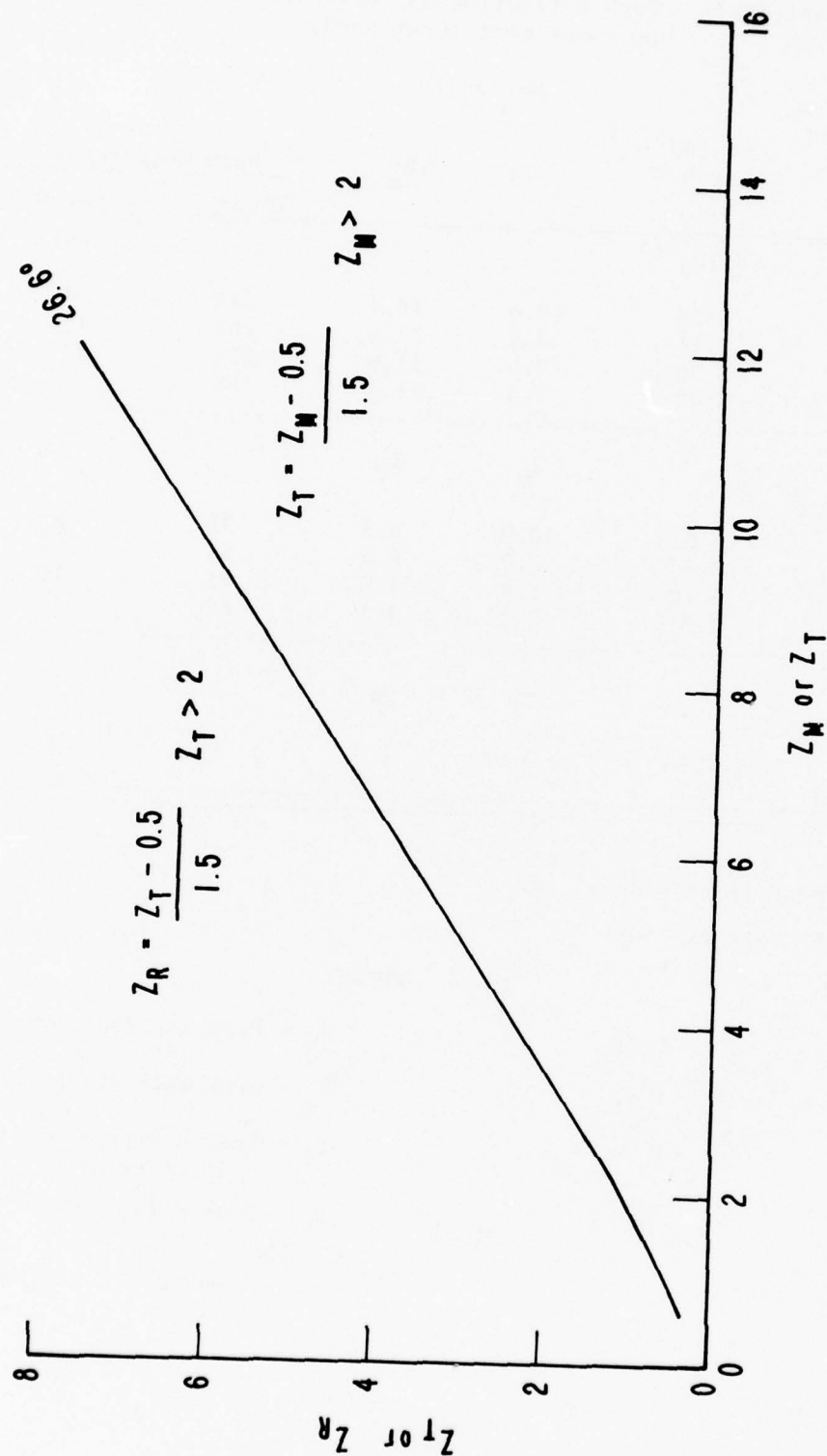
Figure 18. Input Pressure Ratio versus Diffracted Shock Pressure Ratio

in Figure 16. The values determined at scaled distances for gauge positions 6, 15, and 11 are listed in Table XVII for direct comparison with measured values of peak overpressure.

3. Shock Diffraction Pressure on the Rear Slope. When the shock wave passes over the top surface of the structure and starts down the rear surface, a second shock diffraction occurs as shown in Figure 15. The diffracted shock ratio Z_T now becomes the input pressure ratio and the pressure ratio down the rear slope becomes Z_R which is P_R/P_O, where P_R is the peak overpressure on the rear slope and P_O is the atmospheric pressure. A plot of Z_R versus Z_T is presented in Figure 18. Values of Z_T for scaled distances down the rear slope were determined from Figure 18 to determine values of Z_R which are plotted in Figure 16. A value of Z_R determined for Position 12 on the rear slope is listed in Table XVII and converted to P_R for a direct comparison with measured values.

4. Discussion of Theory and Experiment. The determination of peak overpressures on the front slope, top and rear of the model structure was made for the complete series of tests using the theory developed in Reference 7. The comparisons of the theoretical values with measured values is quite good. The overall variation of theory versus experiment is less than ±5 percent.

C. Predicted Pressure and Impulse for ESKIMO V

Two munition storage magazines will be exposed to a hemispherical TNT charge consisting of 9,376, 8-pound demolition blocks making a total weight of 34,054 kg (75,008 lbs). The structure will be placed equidistant 47.2 metres (155 feet) from ground zero (see Figure 19). The suggested gauge locations, distances, predicted peak overpressure, and impulses are listed in Table XVIII. The peak overpressures to be expected on structures A and B are presented as iso-pressure contours in Figure 20. The predicted overpressure impulse values for the full scale test are presented as iso-impulse contours in Figure 21.

The distances and impulse predictions have been scaled for charge weight only and not for the atmospheric pressure or temperature that might be expected at the test site because the test date for ESKIMO V has not been established at this time. The values are noted in both bars and psi for planning convenience and gauge calibration.

Note that the gauge locations on the full size structure do not correspond directly with the gauge locations on the 1/30th or 1/45th scaled models.

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Table XVIII. Suggested Gauge Locations, Predicted
Pressures and Impulses for ESKIMO V

Position Number	Distance from GZ		Peak Overpressure		Positive Impulse	
	Metres	Feet	bar	Psi	bar-Msec	Psi-Msec
*1	30.5	100.0	15.2	220	66.3	962
A2	35.1	115.0	17.9	260	100.0	1450
B3	38.5	126.3	14.1	205	83.0	1204
B4	38.1	125.0	14.6	211	85.0	1233
A5	38.5	126.3	14.1	205	83.0	1204
*6	41.1	135.0	11.0	160	75.0	1088
*7	44.2	145.0	6.34	92	24.8	360
A8	50.1	164.5	4.28	62	41.4	601
A9	47.5	156.0	5.52	80	43.0	624
*10	47.2	155.0	6.00	87	45.6	661
B11	48.5	156.0	5.52	80	43.0	624
B12	48.8	160.0	4.14	60	40.3	585
*13	50.3	165.0	4.62	67	40.4	587
B14	53.3	175.0	3.45	50	36.6	530
A15	56.4	185.0	2.34	34	36.0	522
A16	65.5	215.0	2.55	37	26.6	386

*Common to Structures A and B

NOTE: Gauge positions on ESKIMO V structure not all equivalent to gauge positions on Models.

Gauge Positions
ESKIMO V = MODEL

1 = 1
2 = 2
3 = 3
4 = 14
5 = 4
6 = 5
7 = 6
8 = 7
9 = 8
10 = 15
11 = 9
12 = 10
13 = 11
14 = -
15 = 12
16 = 13

58
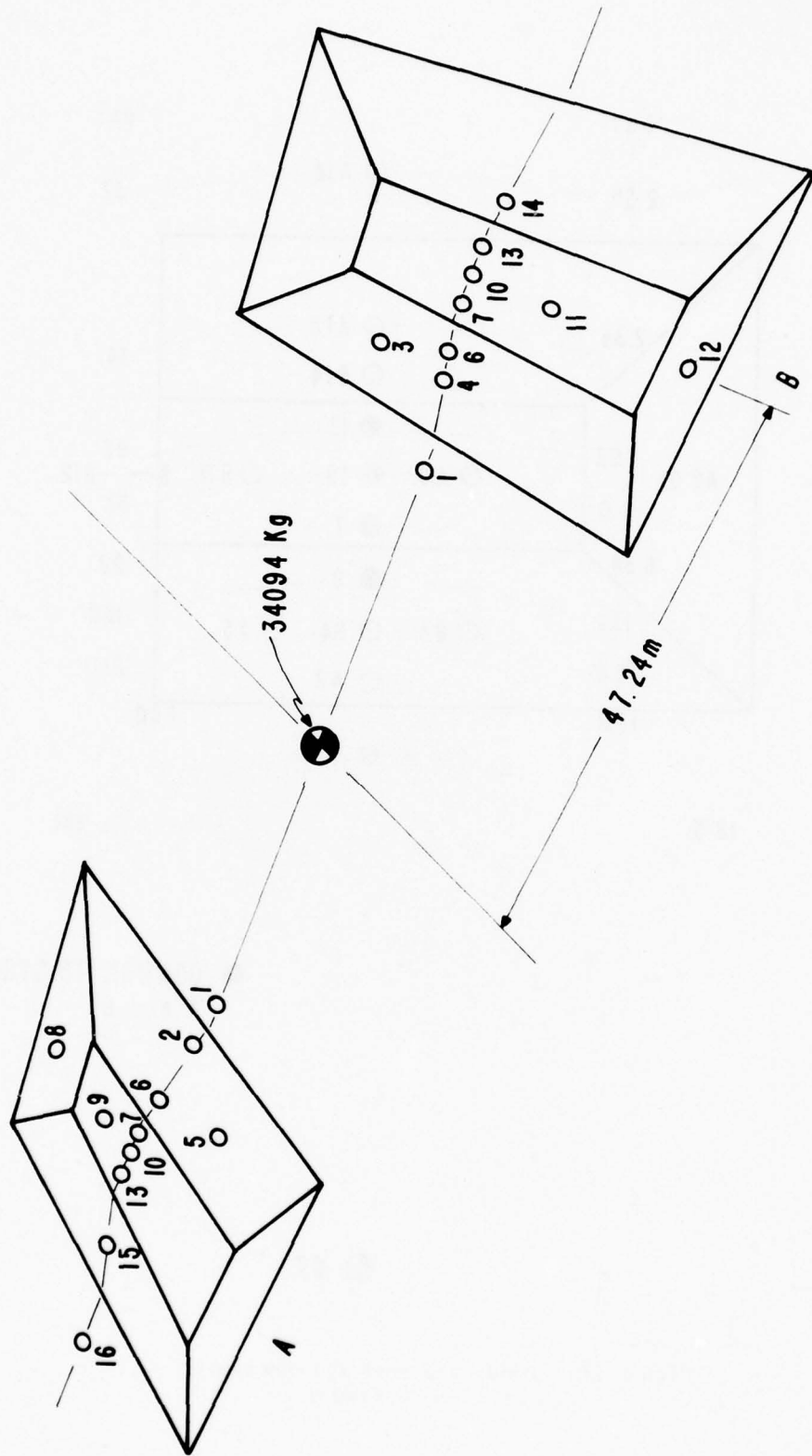
Figure 19. Eskimo A Test Layout
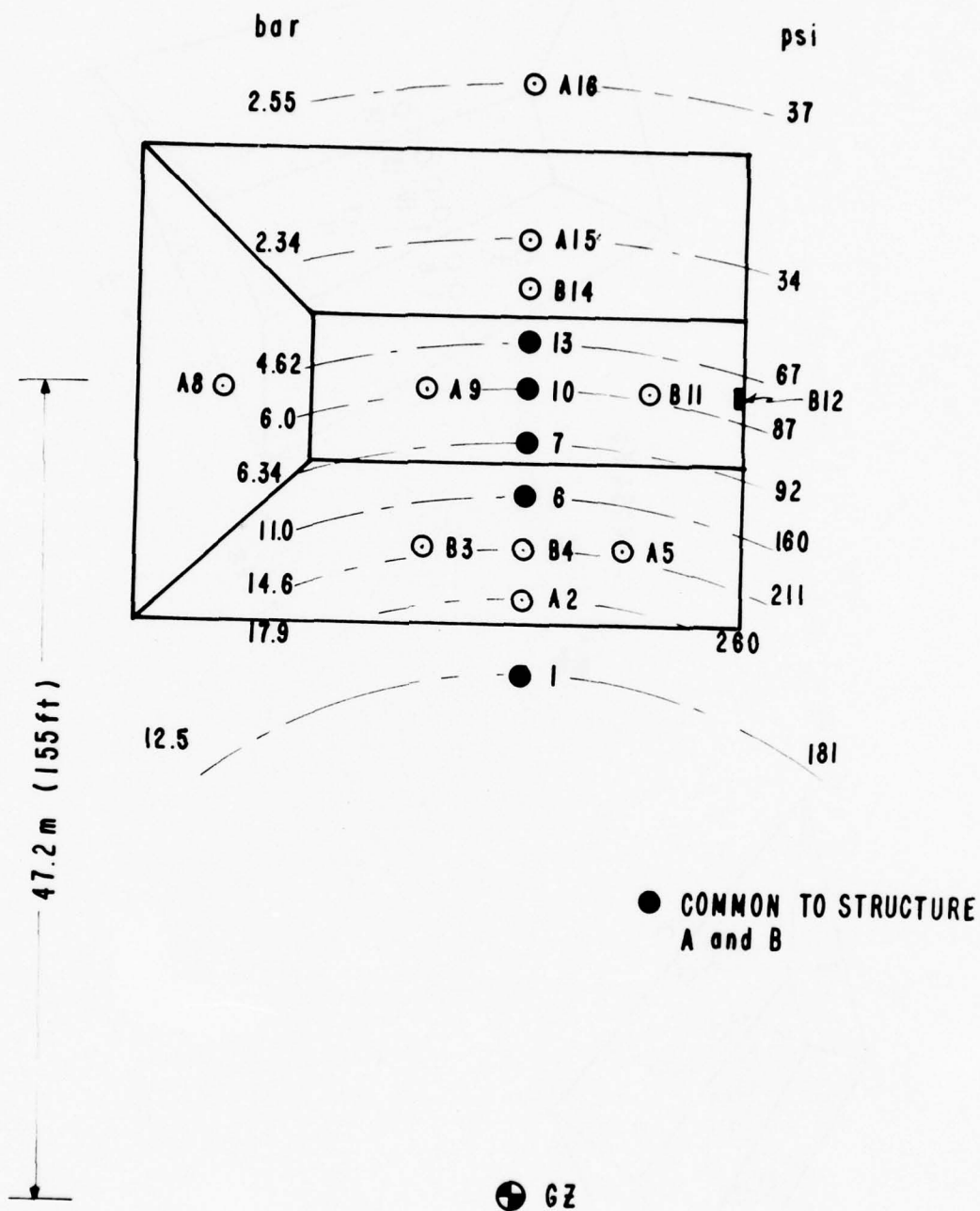
Figure 20. Predicted Peak Overpressure
Contours for ESKIMO V

bar -ms   psi - ms

26.6 ─ ─ ─ ─ ─ ─ ─ ⊙ A 16 ─ ─ ─ ─ ─ ─ ─ 386

36.0 ⊙ ─ ─ ─ ─ ─ ⊙ A15 ─ ─ ─ ─ ─ ─ 522

                        ⊙ B 14

                        ● 13   587
40.1

A8 ⊙   ⊙ A9 ─ ● 10 ─ ⊙ B11   ◼ ← B 12

45.6 ─ ─ ─ ─ ─ ─ ● 7 ─ ─ ─ ─ ─ ─ 661
24.8   360

                        ● 6   1088
75.0   ⊙ B3 ⊙ B 4 ─ ⊙ A5

85.0 ─ ─ ─ ─ ─ ─ ⊙ A2 ─ ─ ─ ─ ─ ─ 1233

100 ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ 1450

                        ●

66.3 ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ 962

47.2m (155 ft.)

                                        ● COMMON TO STRUCTURE
                                          A & B

                        ⊕ GZ

Figure 21.   Predicted Overpressure Impulse
             Contours for ESKIMO V

61

ACKNOWLEDGMENTS

62

APPENDIXES

PRESSURE VERSUS TIME DATA

The Appendixes show the average overpressure versus time recorded at the gage positions instrumented on the 1/30 and 1/45 scale models. They are divided into four sections for presenting the different charge weights and model scales. The divisions are as follows:

Appendix A - Model Scale 1/30 - Charge Weight .454 kg Pentolite

Appendix B - Model Scale 1/30 - Charge Weight .908 kg Pentolite

Appendix C - Model Scale 1/30 - Charge Weight 1.135 kg Pentolite

Appendix D - Model Scale 1/45 - Charge Weight .454 kg Pentolite.

All plots of overpressure versus time are presented in units of bars versus milliseconds, where the bar is obtained by dividing pounds per square inch (psi) by 14.5. The bar multiplied by 100 is equivalent to one kilopascal.

APPENDIX A

Series I - Model Scale 1/30 Charge Weight 0.454 kg Pentolite

APPENDIX A - LIST OF ILLUSTRATIONS

SERIES I
POSITION I
IMPULSE - 1.67 bar-ms

Figure A-1. Overpressure versus Time, Position 1

67
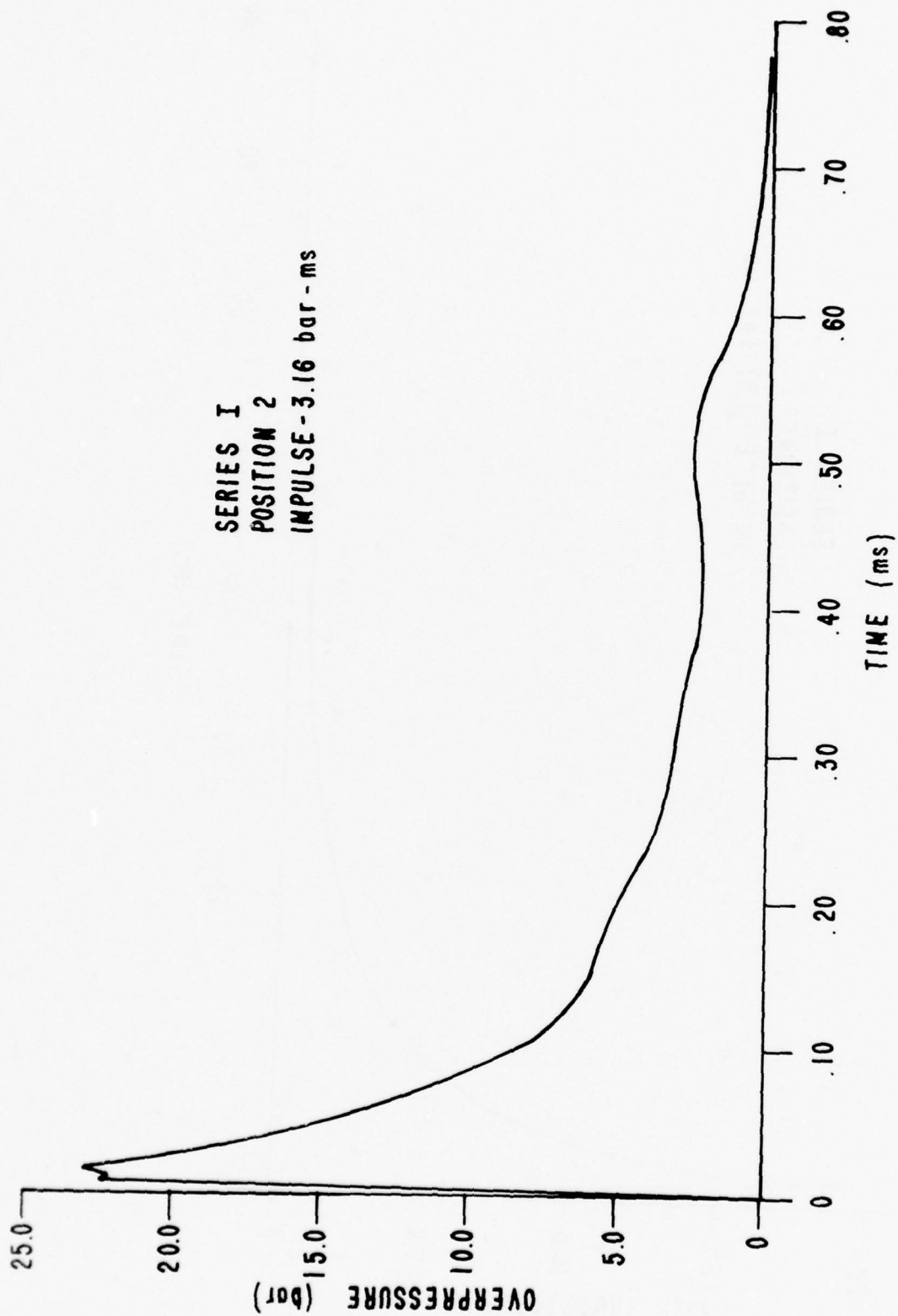
Figure A-2. Overpressure versus Time, Position 2

SERIES I
POSITION 3
IMPULSE - 2.45 bar - ms

OVERPRESSURE (bar)

TIME (ms)
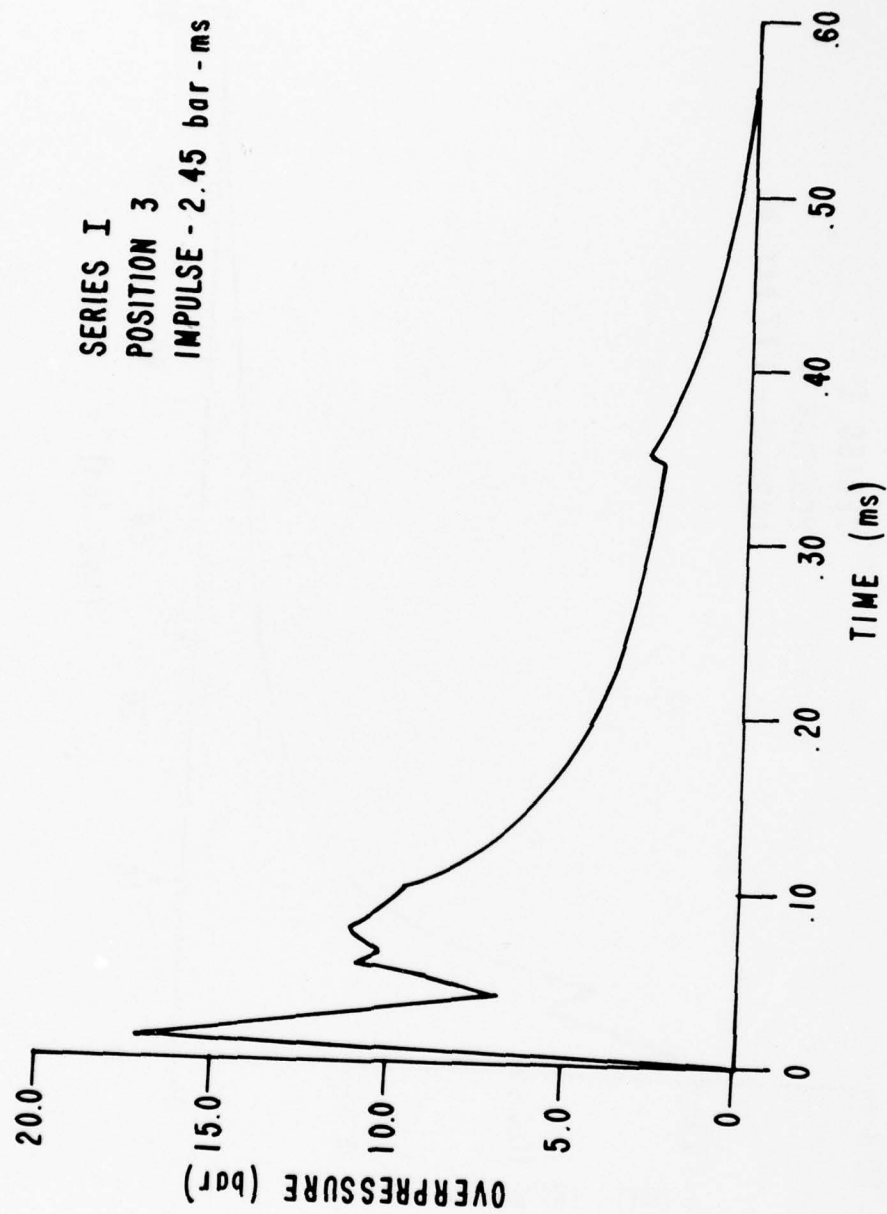
Figure A-5. Overpressure versus Time, Position 3

69
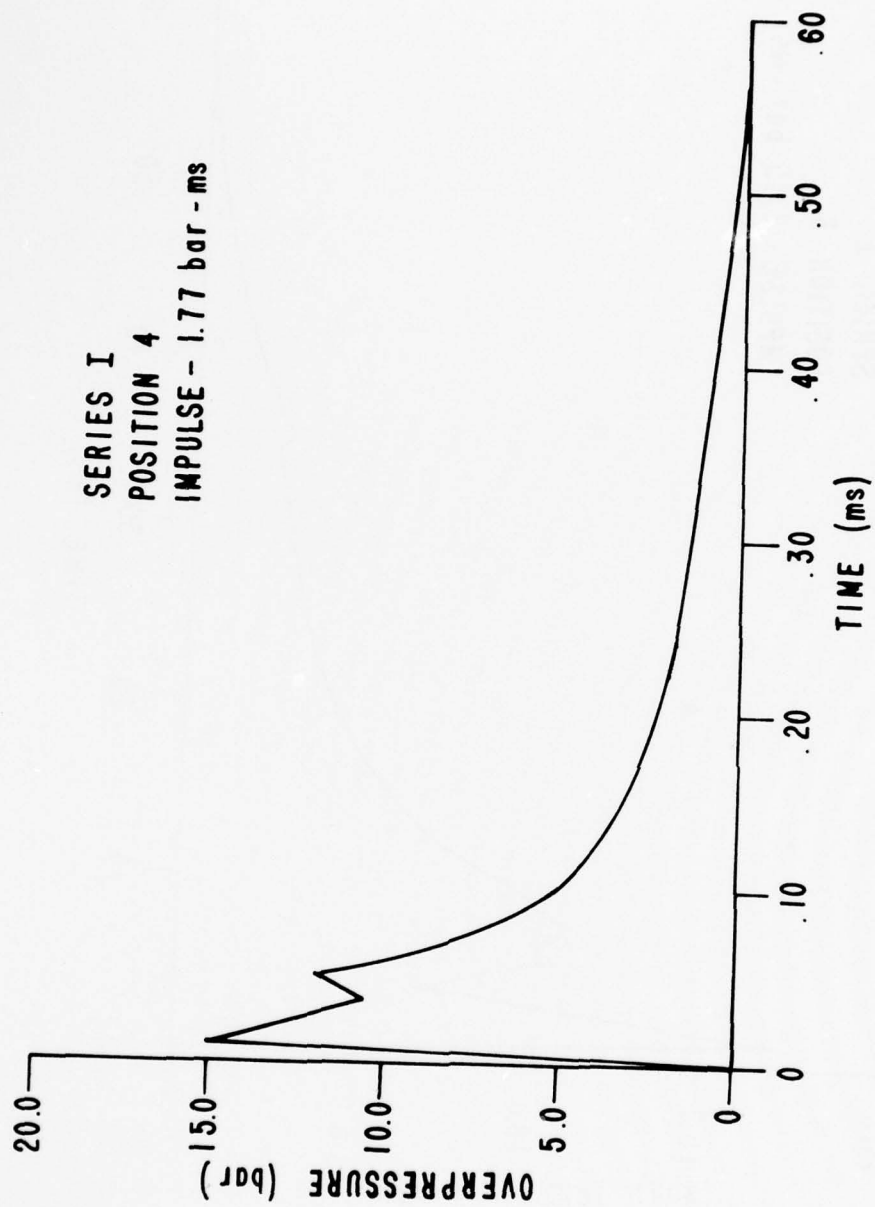
Figure A-4. Overpressure versus Time, Position 4
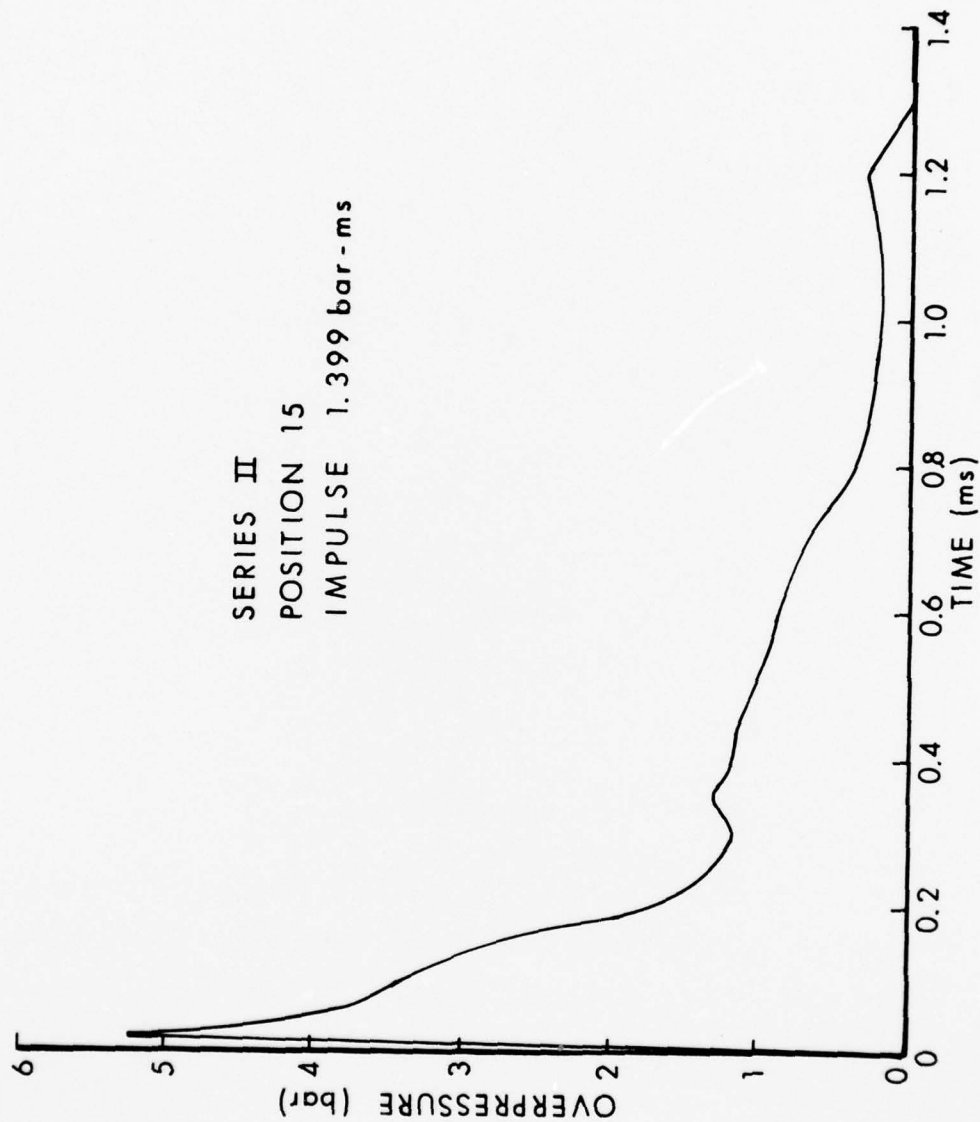
70

Figure A-5. Overpressure versus Time, Position 5

SERIES I
POSITION 6
IMPULSE .655 bar-ms
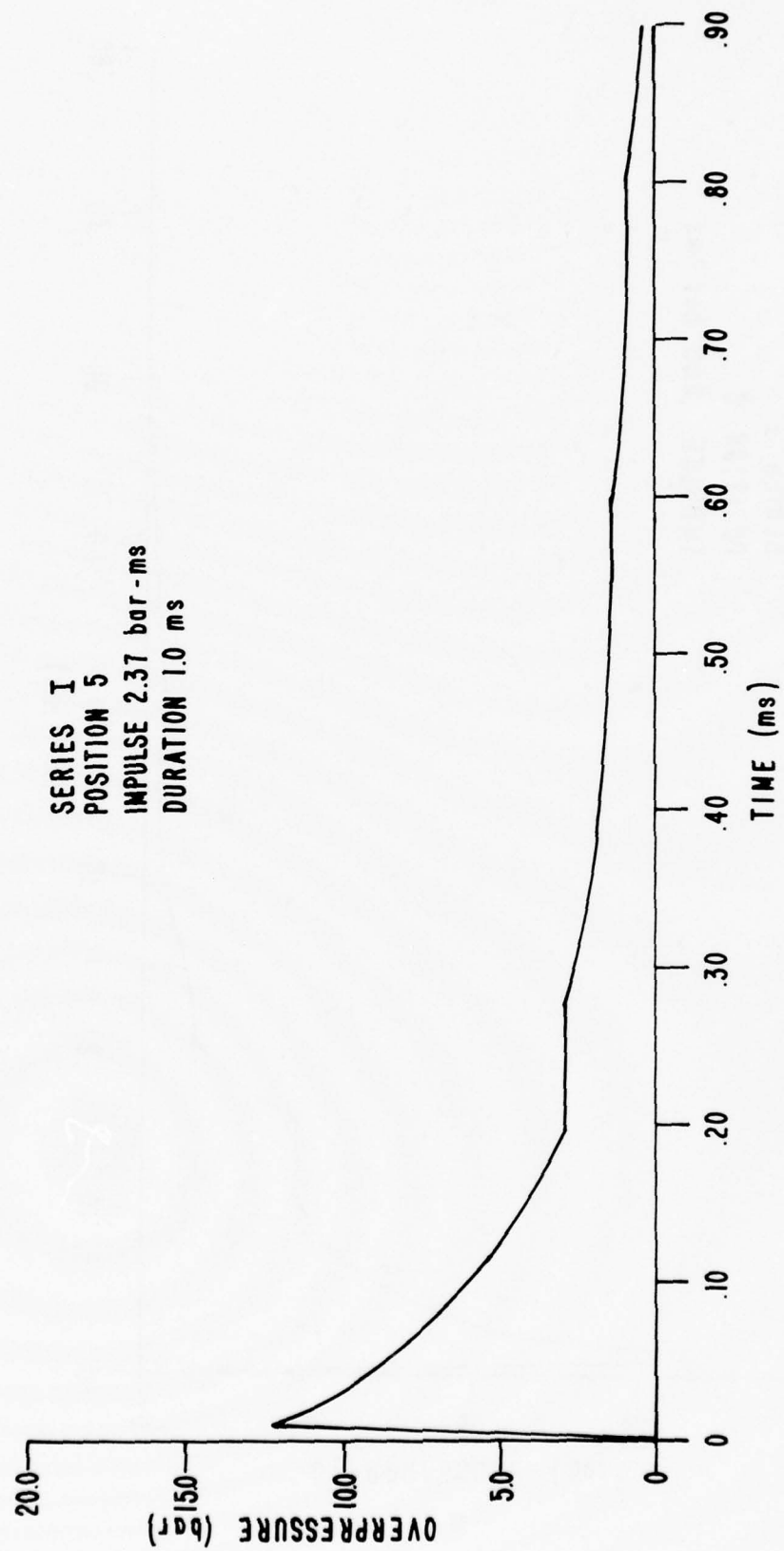
Figure A-6. Overpressure versus Time, Position 6

72

SERIES I
POSITION 7
IMPULSE .742 bar-ms
DURATION 1.1 ms

OVERPRESSURE (bar)

TIME (ms)
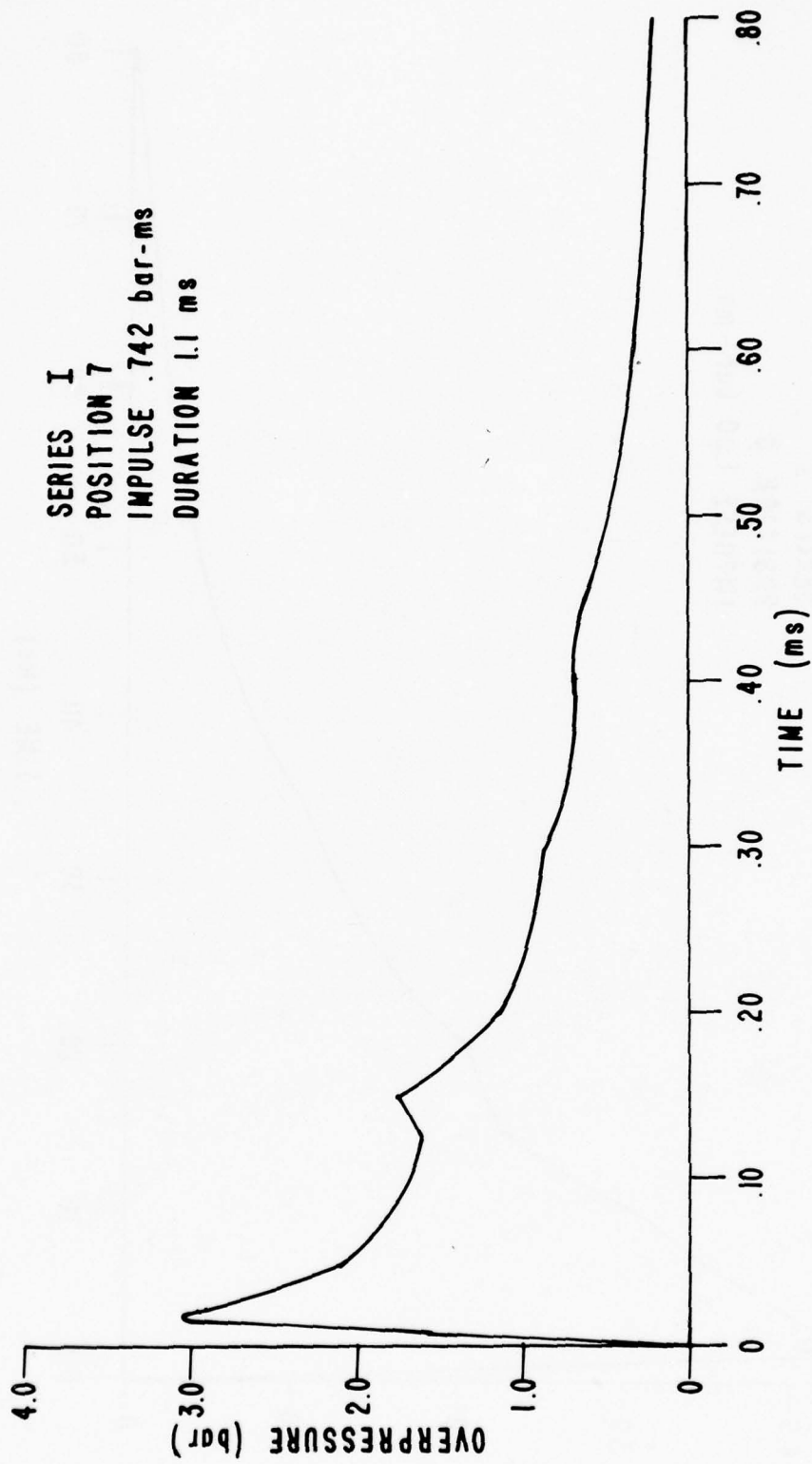
Figure A-7. Overpressure versus Time, Position 7

SERIES I
POSITION 8
IMPULSE 1.00 bar-ms

TIME (ms)
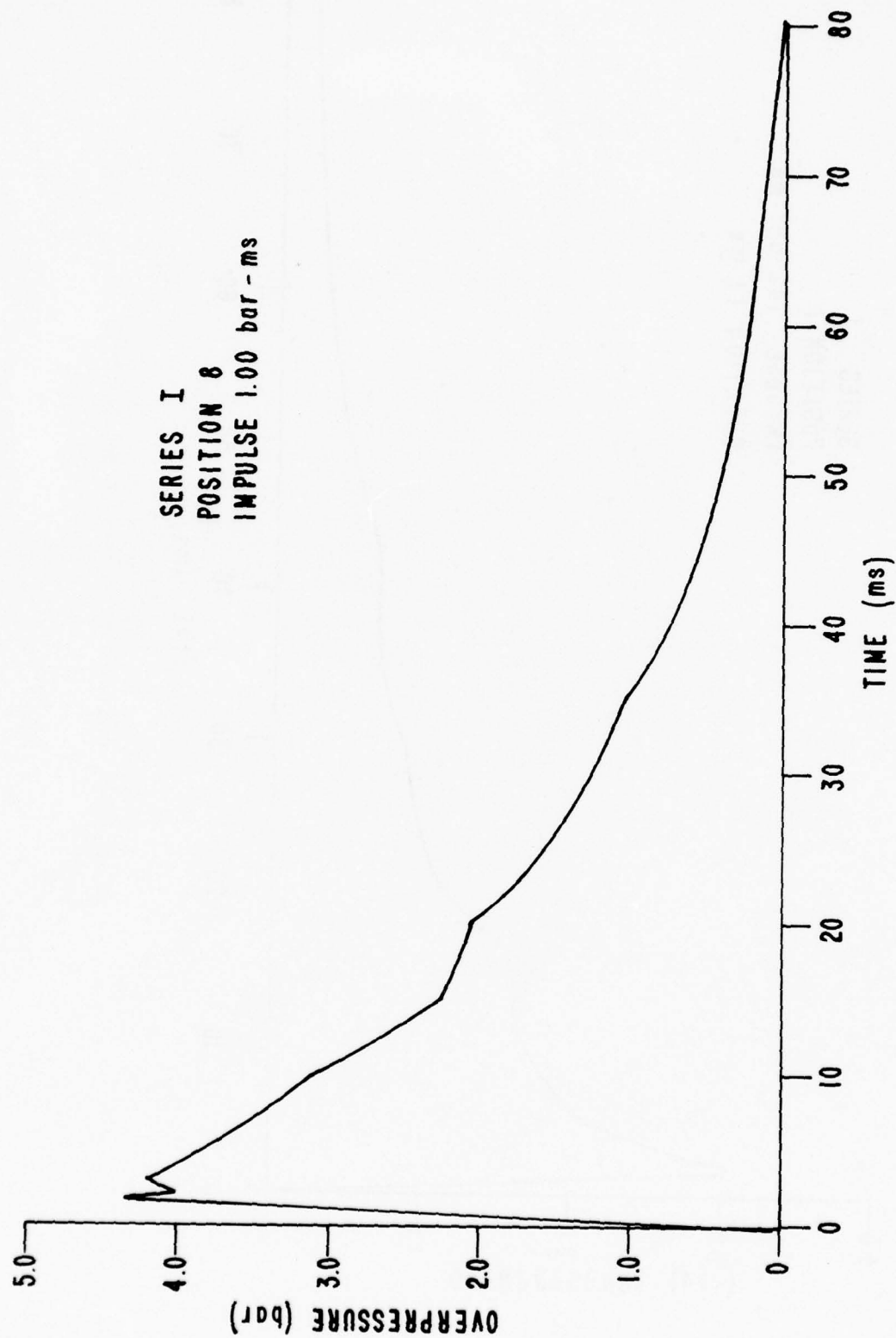
OVERPRESSURE (bar)

Figure A-8. Overpressure versus Time, Position 8

74

SERIES I
POSITION 9
IMPULSE 0.966 bar - ms
DURATION 1.0 ms
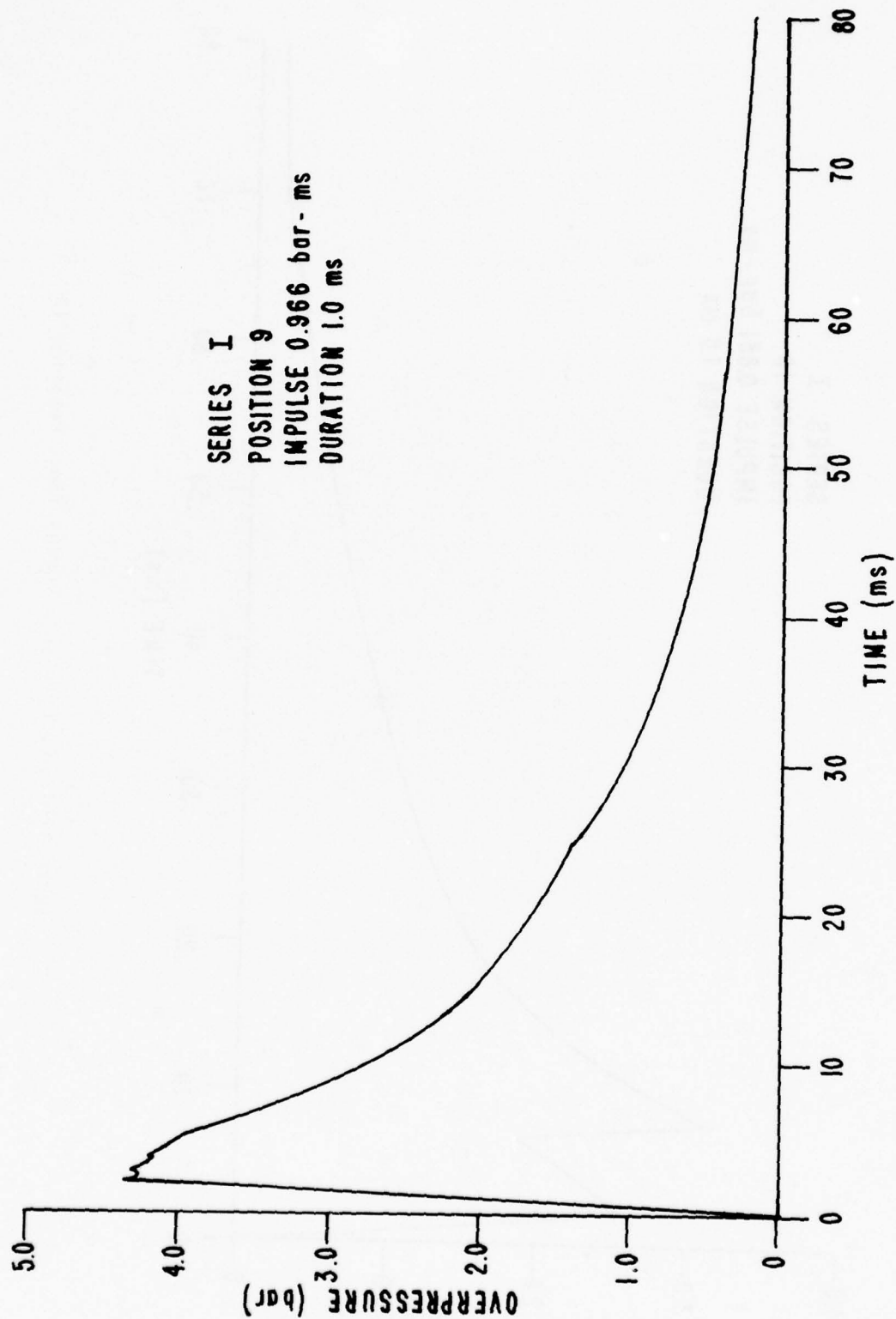
Figure A-9. Overpressure versus Time, Position 9

75

SERIES I
POSITION 10
IMPULSE 0.831 bar-ms
DURATION 1.0 ms
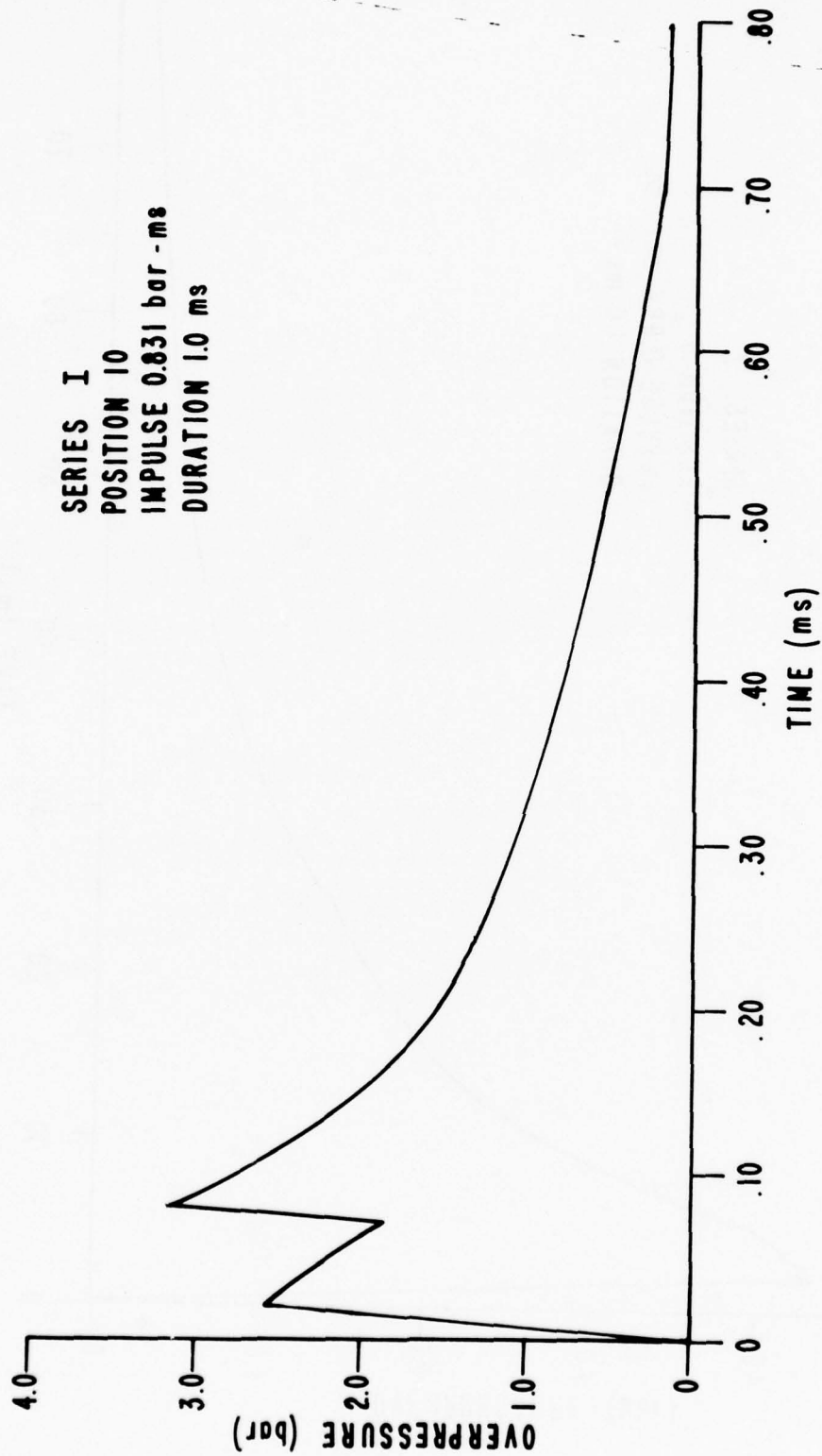
Figure A-10. Overpressure versus Time, Position 10

76

SERIES I
POSITION 11
IMPULSE 0.995 bar-ms

OVERPRESSURE (bar)

TIME (ms)

Figure A-11. Overpressure versus Time, Position 11

SERIES I
POSITION 12
IMPULSE 0.578 bar-ms
DURATION 1.20 ms
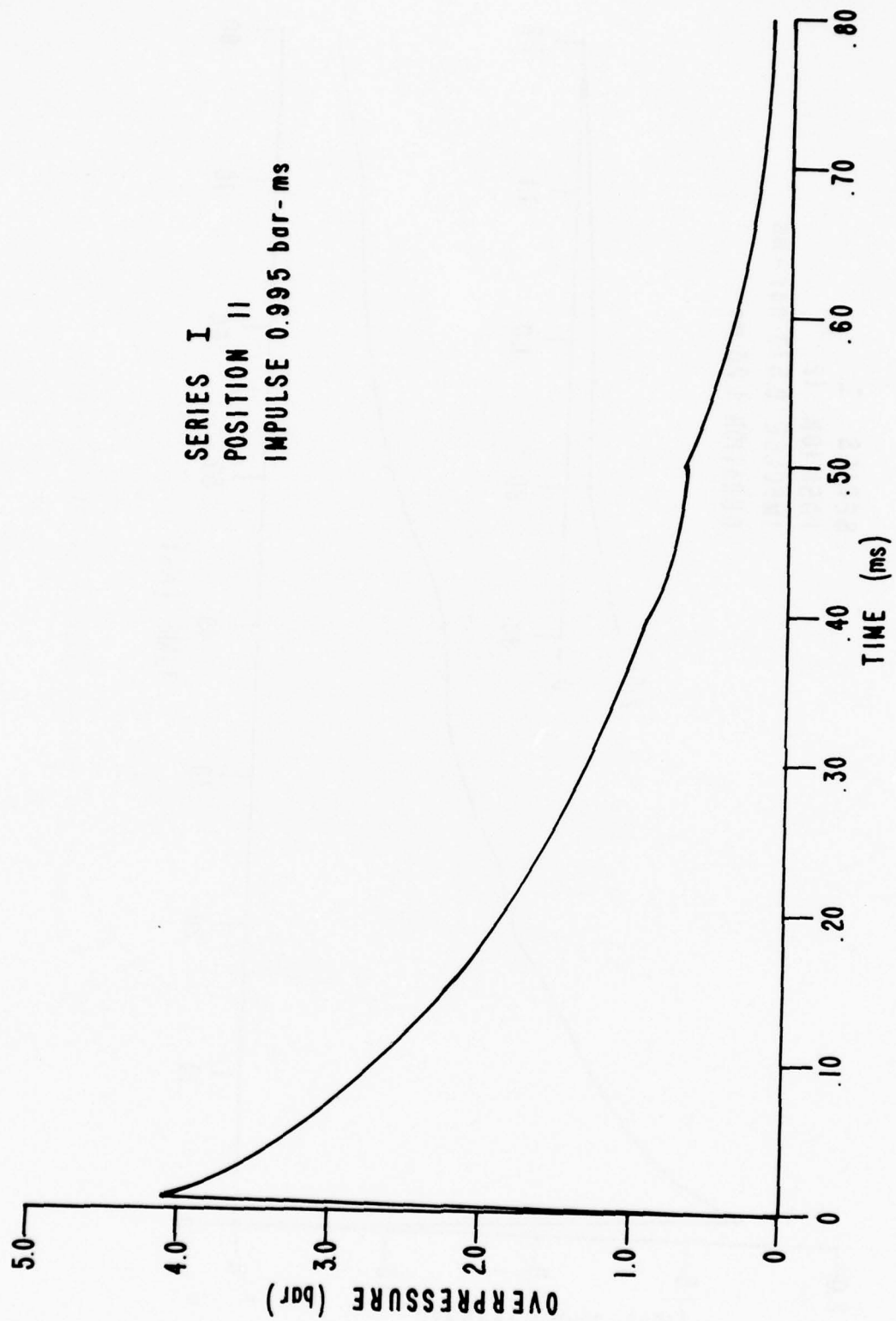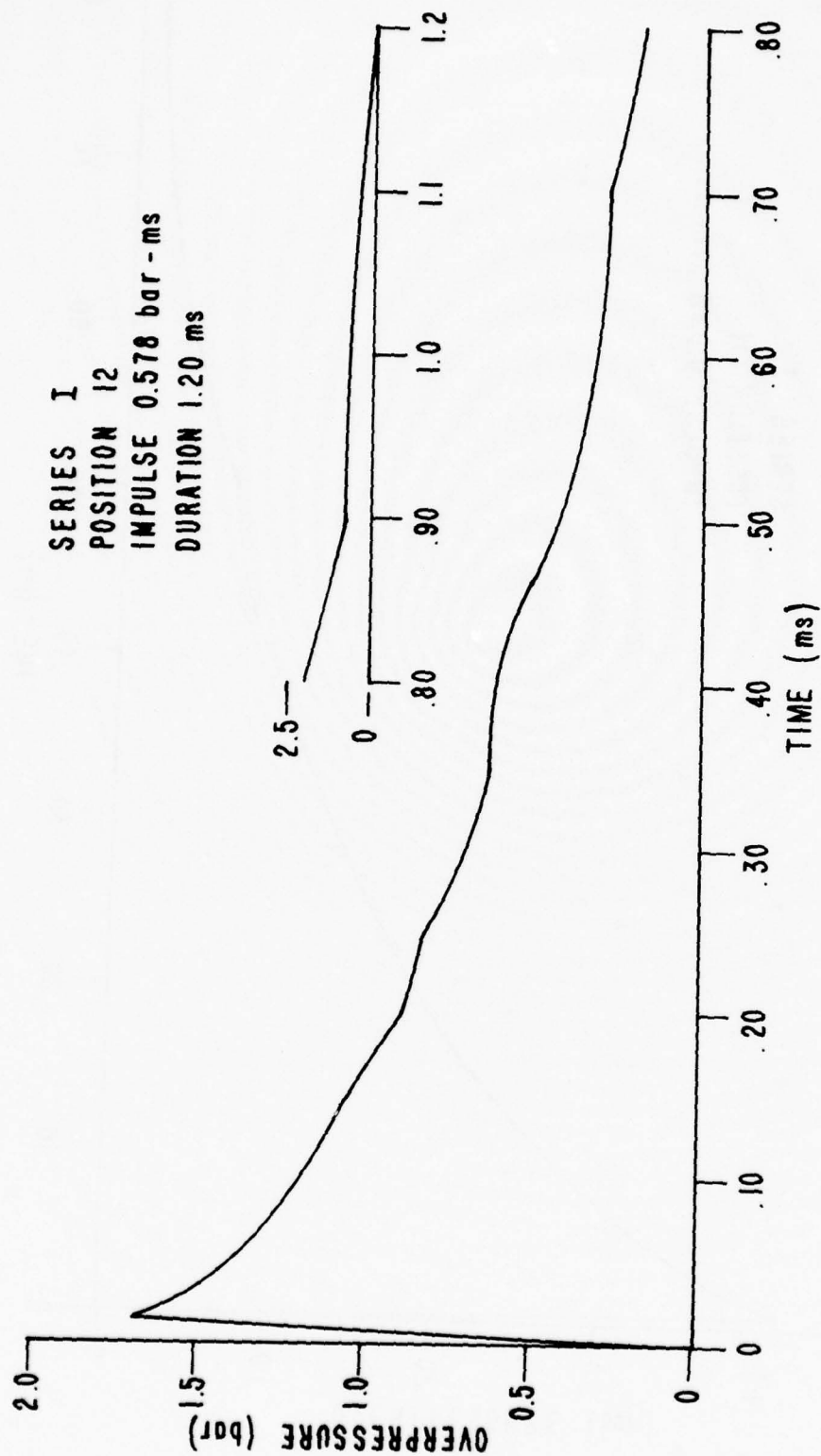
Figure A-12. Overpressure versus Time, Position 12

78

SERIES I
POSITION 13
IMPULSE 0.681 bar-ms

OVERPRESSURE (bar)

TIME (ms)

Figure A-13. Overpressure versus Time, Position 13

79

SERIES I
POSITION 14
IMPULSE 2.51 bar-ms

OVERPRESSURE (bar)

TIME (ms)

Figure A-11. Overpressure versus Time, Position 14

SERIES I
POSITION 15
IMPULSE 1.05 bar-ms
DURATION 1.10 ms

OVERPRESSURE (bar)

TIME (ms)
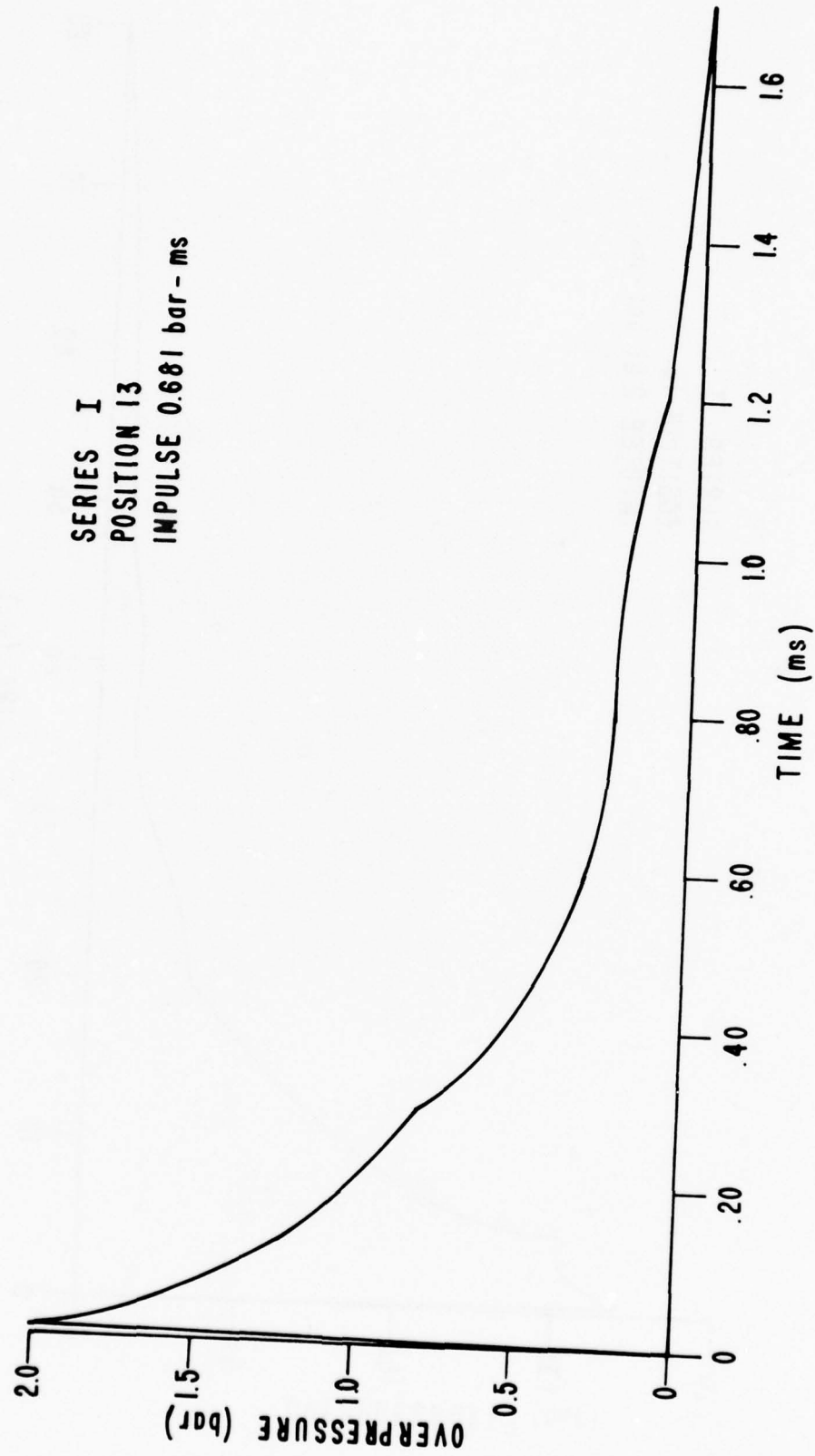
Figure A-15. Overpressure versus Time, Position 15

81

APPENDIX B

Series II - Model Scale 1/30 Charge Weight 0.908 kg Pentolite

APPENDIX B - LIST OF ILLUSTRATIONS

SERIES II
POSITION 1
IMPULSE 2.709 bar-ms

OVERPRESSURE (bar)

TIME (ms)

Figure B-1. Overpressure versus Time Position 1

85

SERIES II
POSITION 2
IMPULSE 4.360 bar-ms

OVERPRESSURE (bar)

TIME (ms)
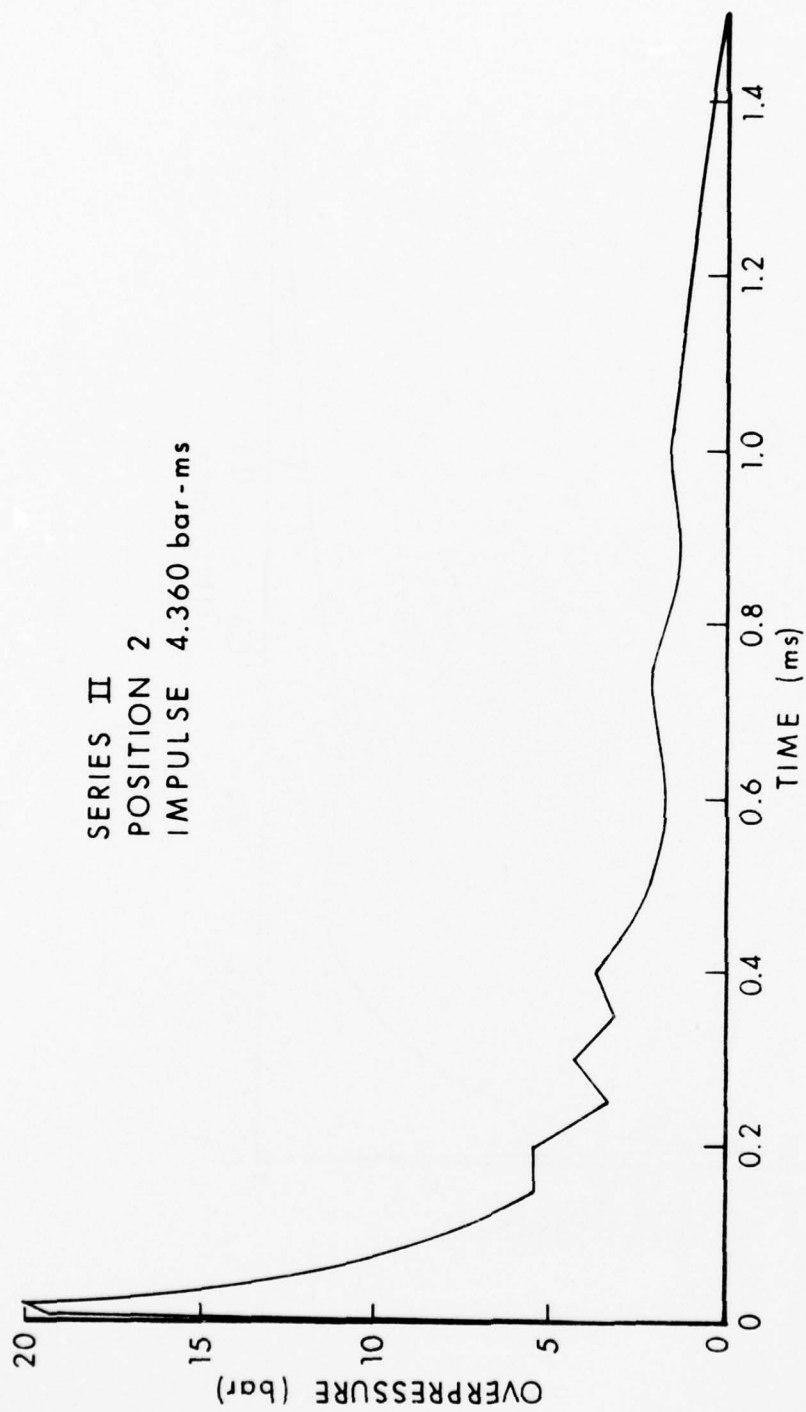
Figure B-2. Overpressure versus Time, Position 2

SERIES II
POSITION 5
IMPULSE 2.818 bar-ms
DURATION 1.0 ms
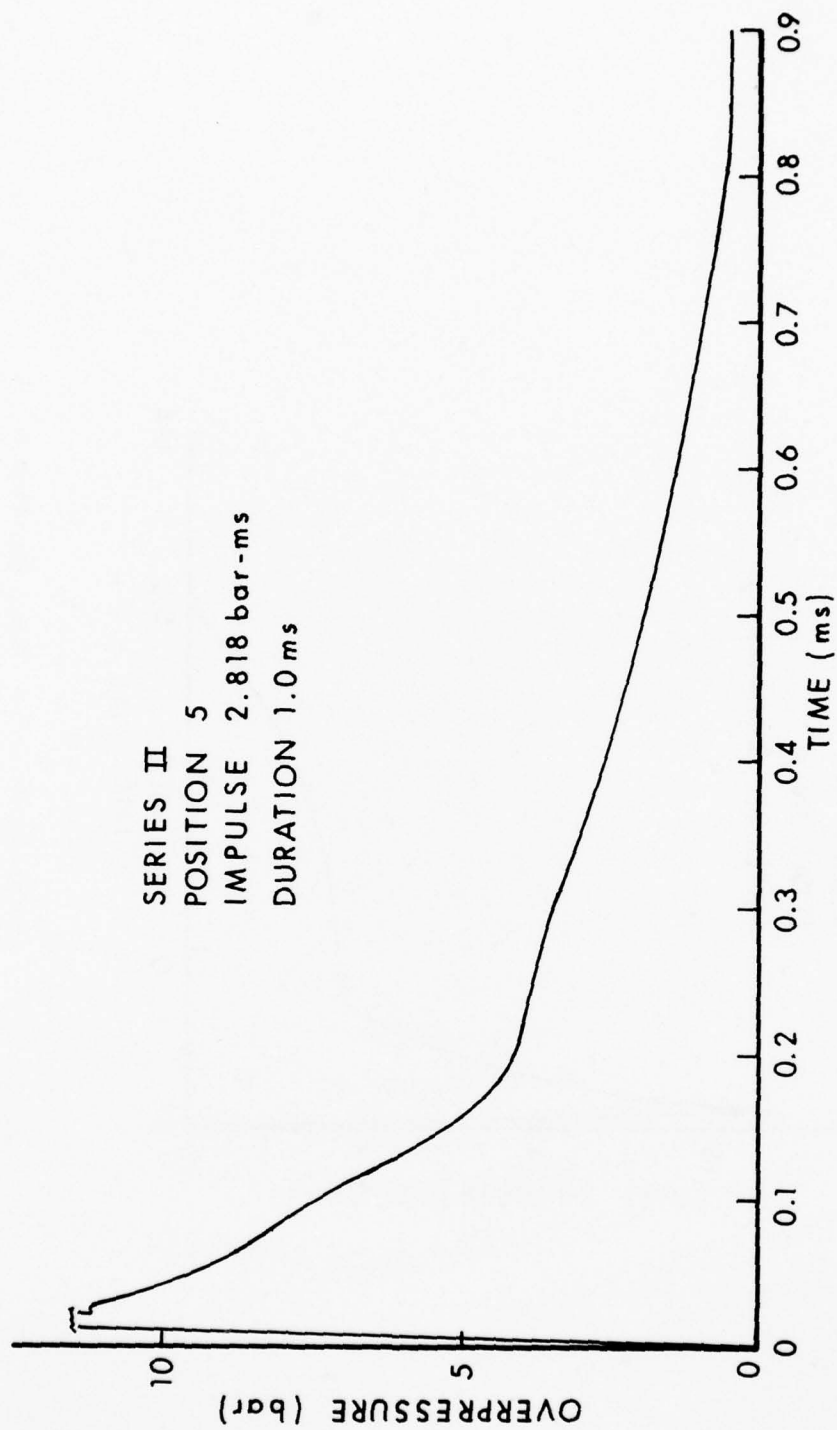
Figure B-3. Overpressure versus Time, Position 5

SERIES II
POSITION 6
IMPULSE 0.564 bar-ms
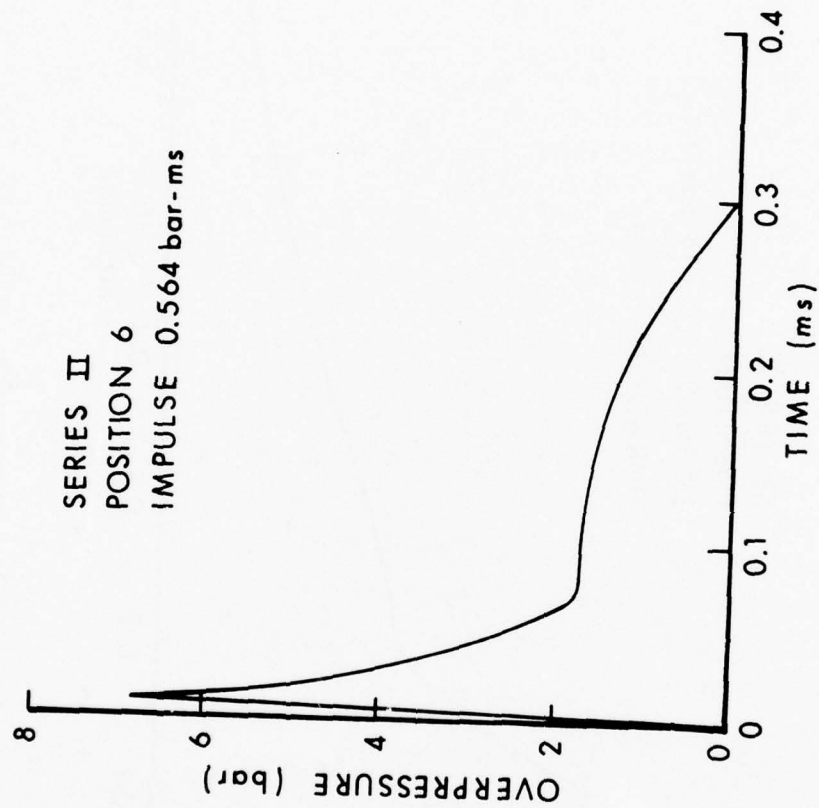
Figure B-4. Overpressure versus Time, Position 6

88

SERIES II
POSITION 7
IMPULSE 1.045 bar-ms

OVERPRESSURE (bar)

TIME (ms)
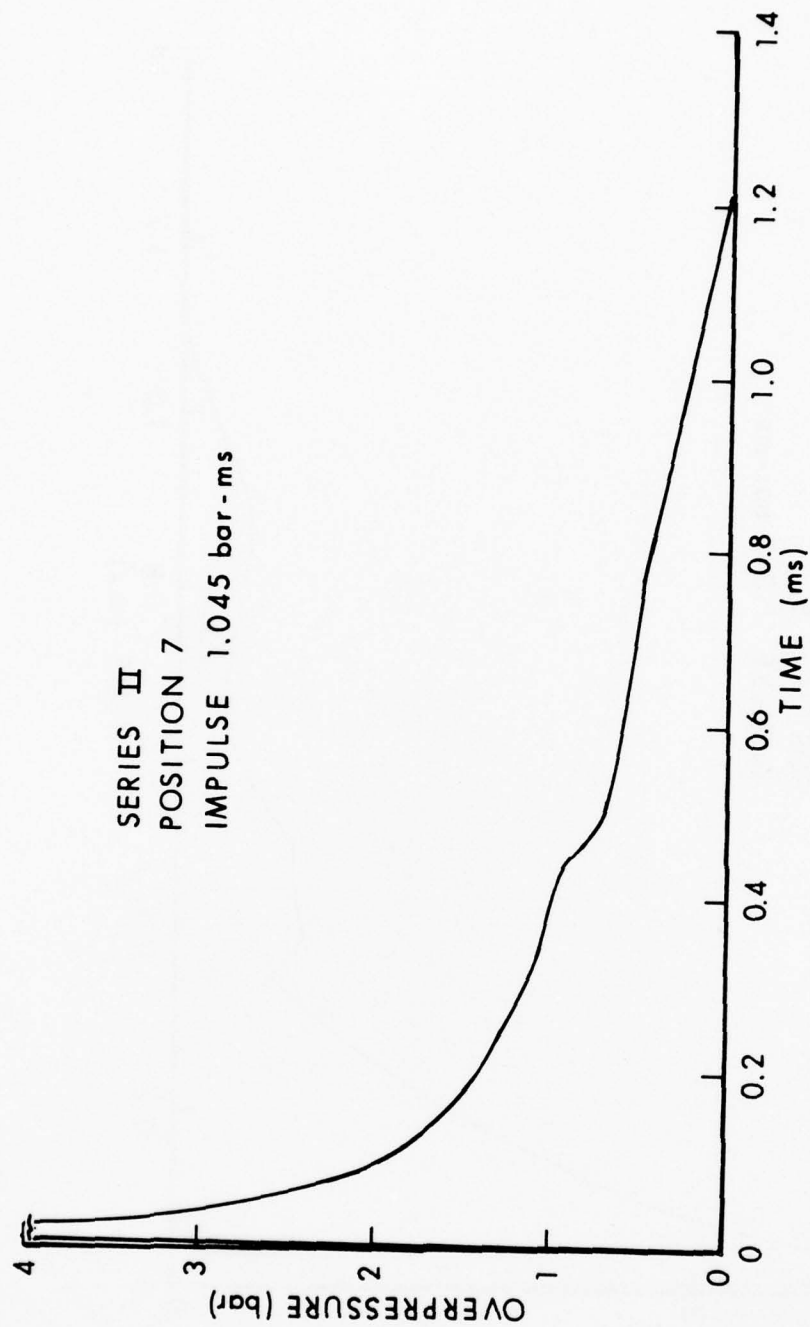
Figure B-5. Overpressure versus Time, Position 7

89

SERIES II
POSITION 8
IMPULSE 1.045 bar-ms
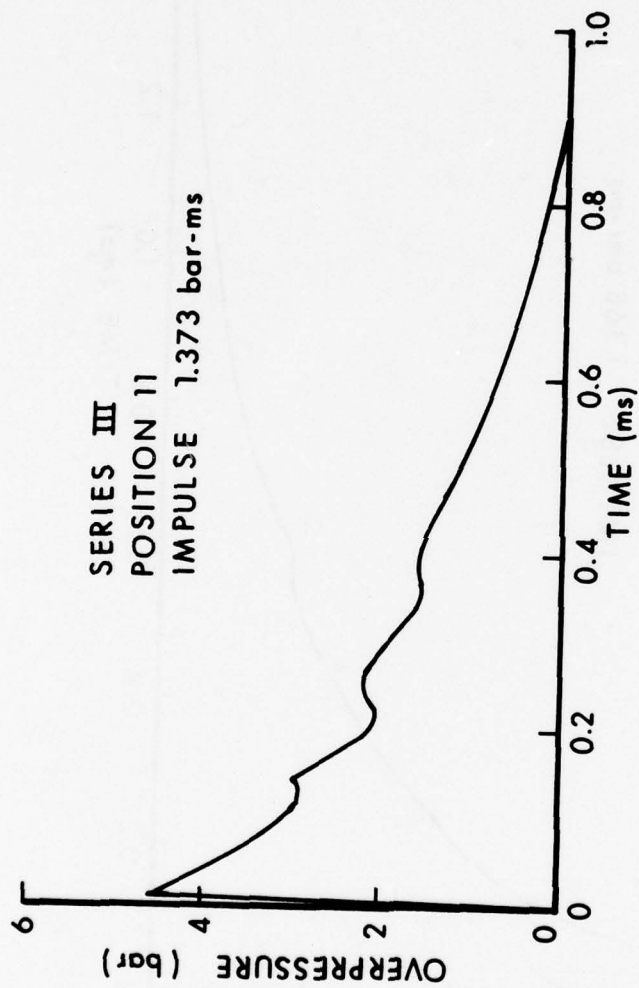
OVERPRESSURE (bar)

TIME (ms)
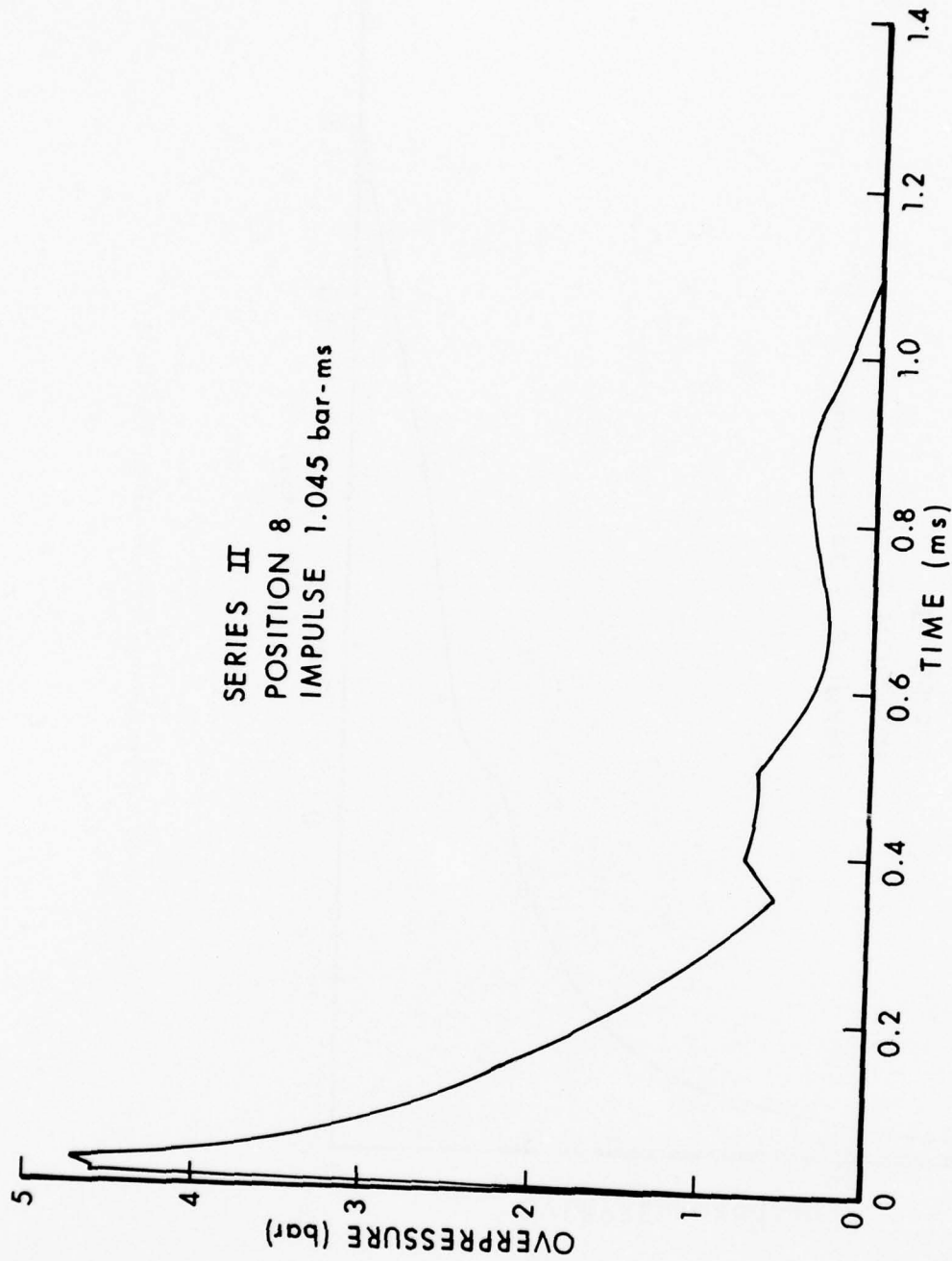
Figure B-6. Overpressure versus Time, Position 8

90
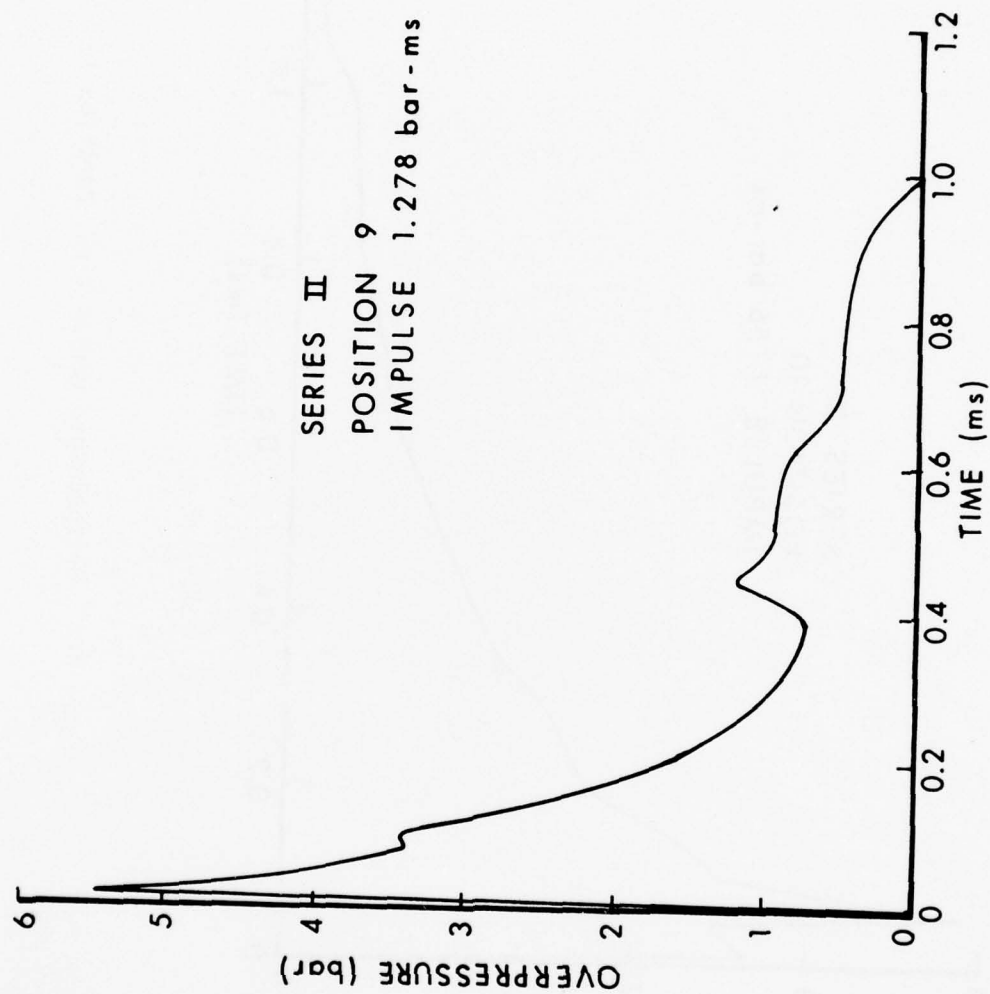
Figure B-7. Overpressure versus Time, Position 9
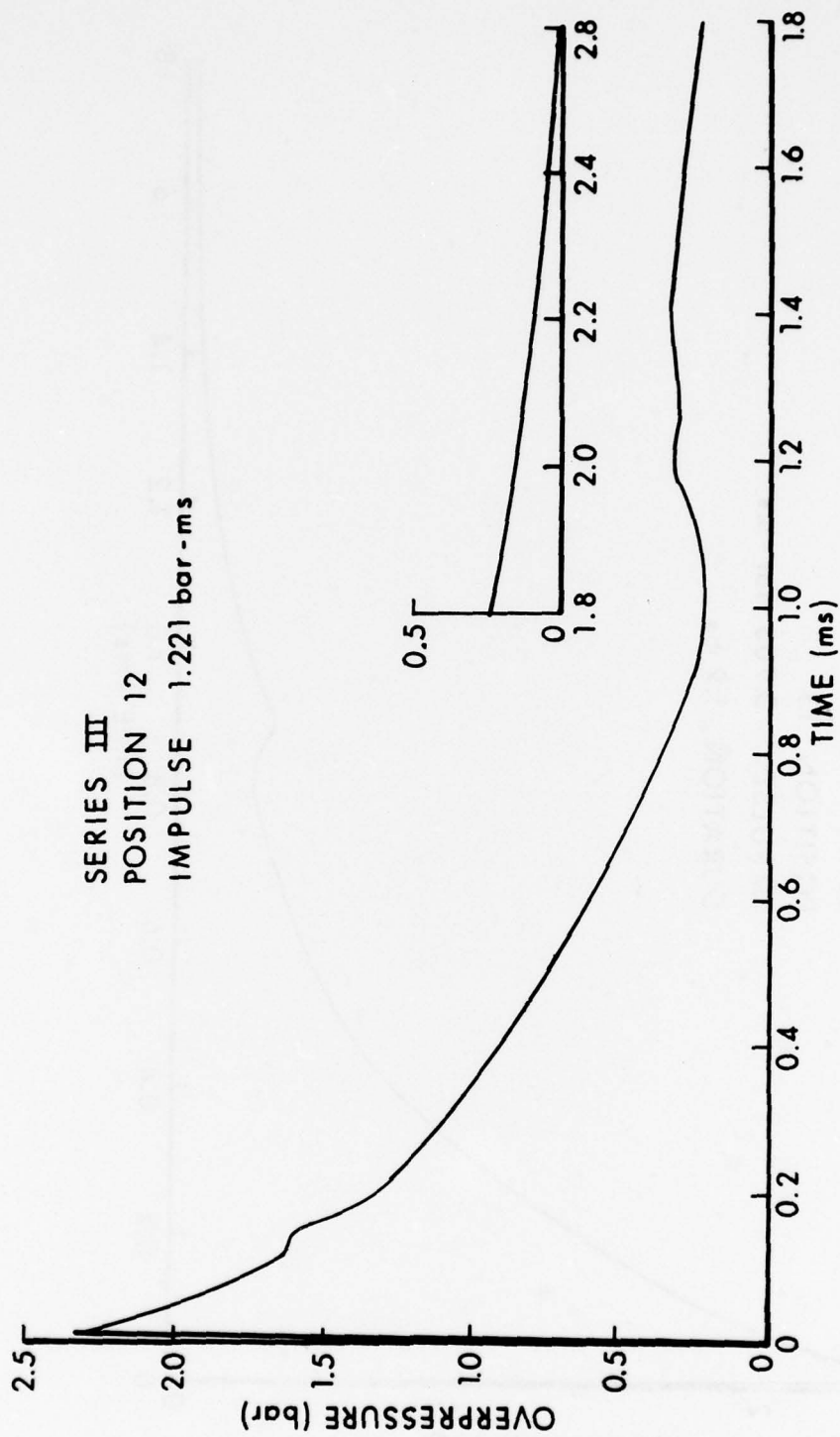
91
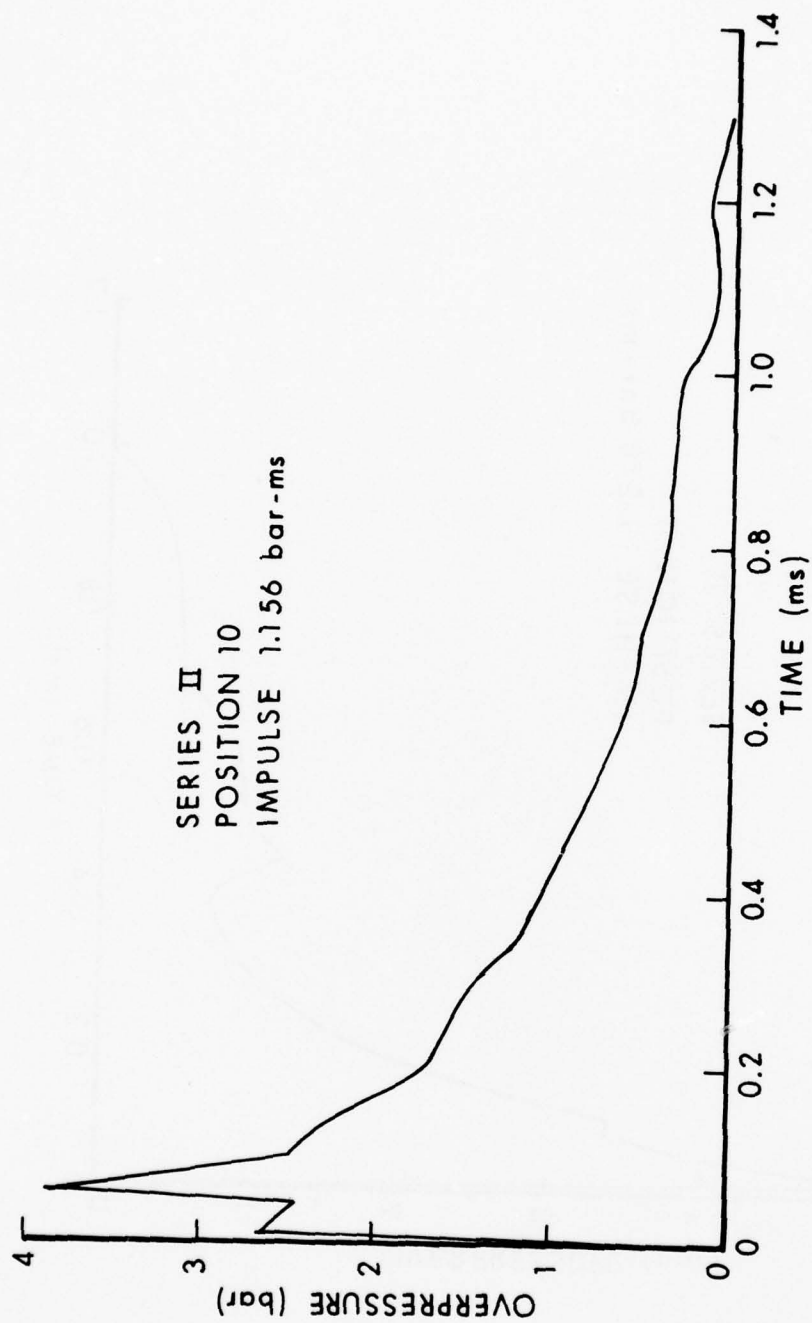
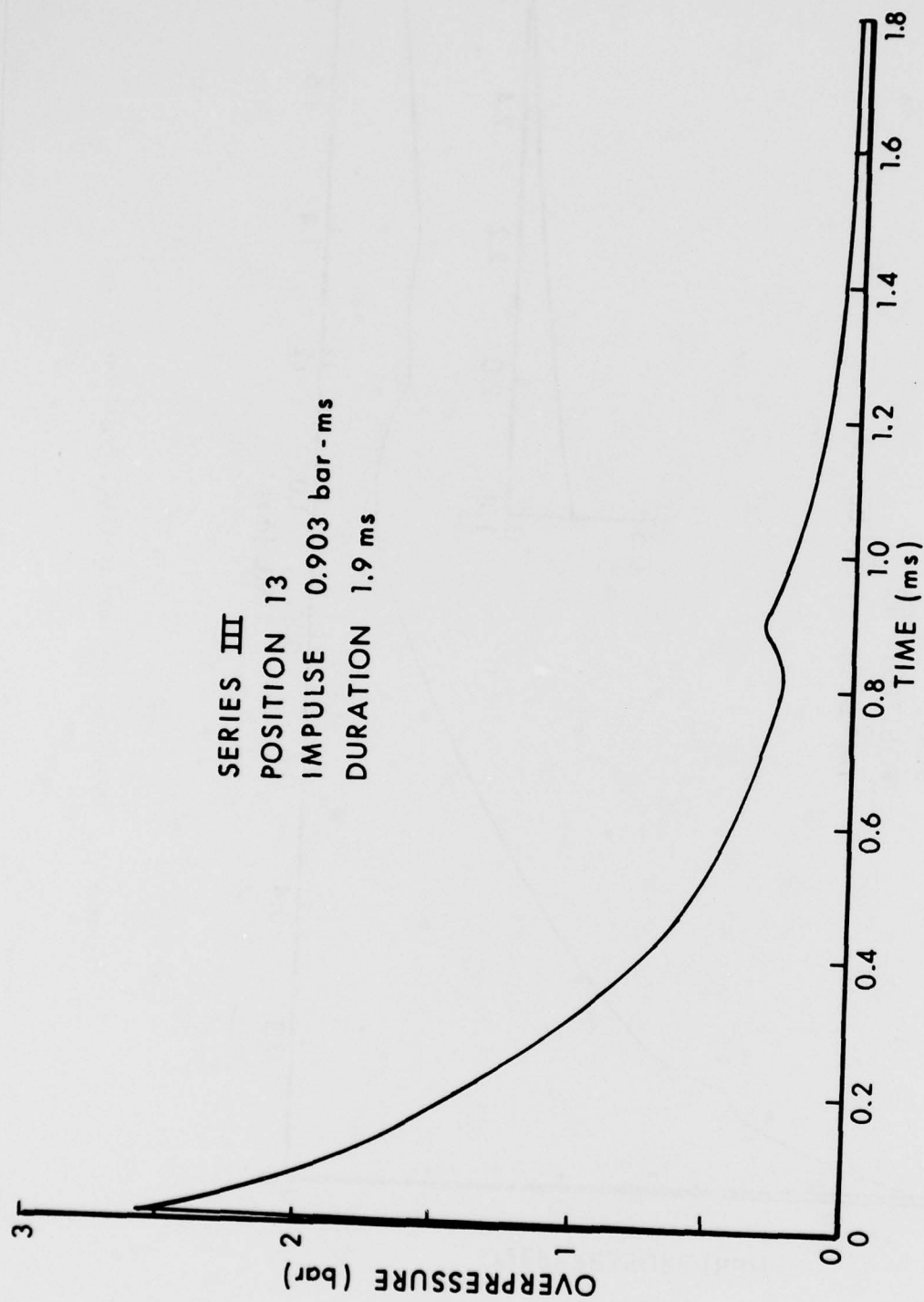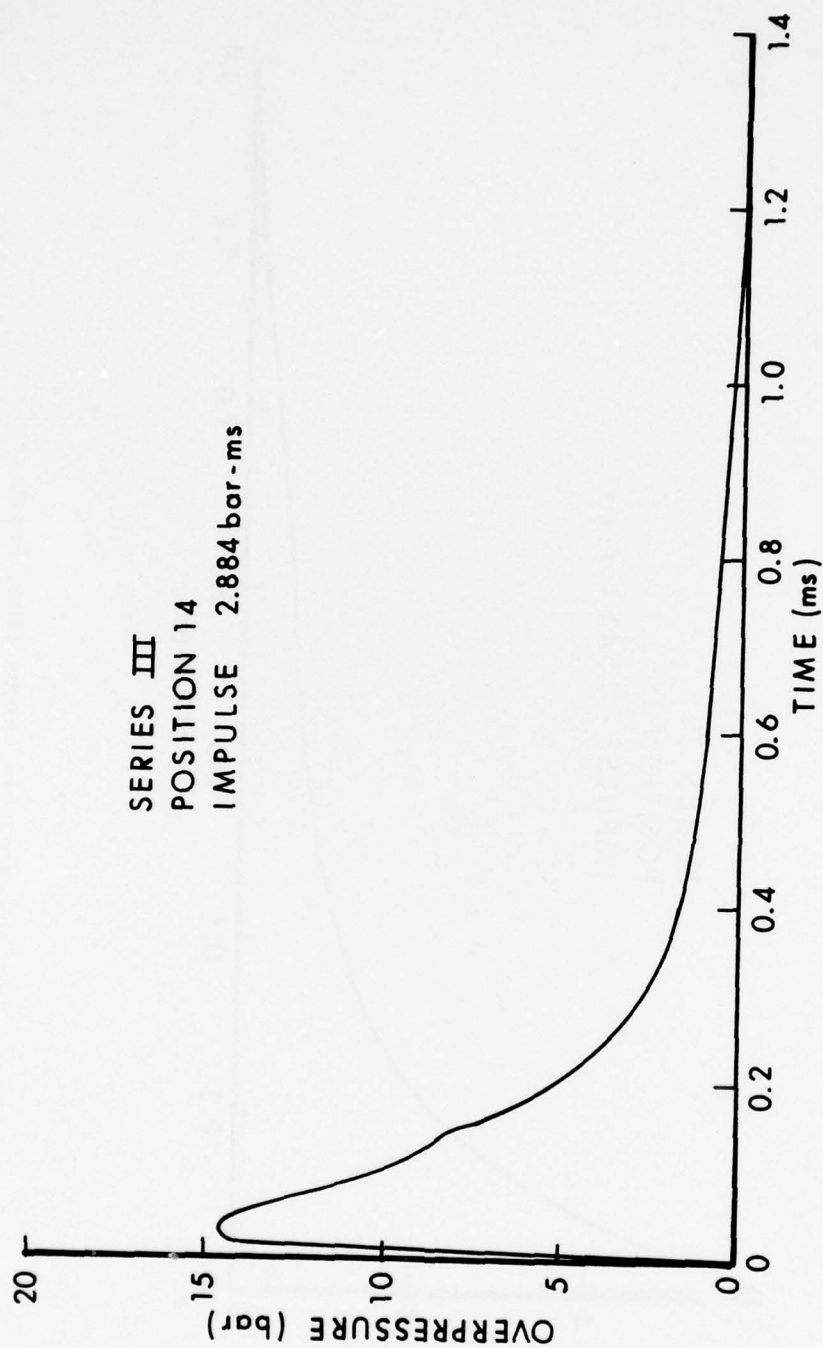Figure B-8. Overpressure versus Time, Position 10

SERIES II
POSITION 11
IMPULSE 1.108 bar-ms

OVERPRESSURE (bar)

TIME (ms)
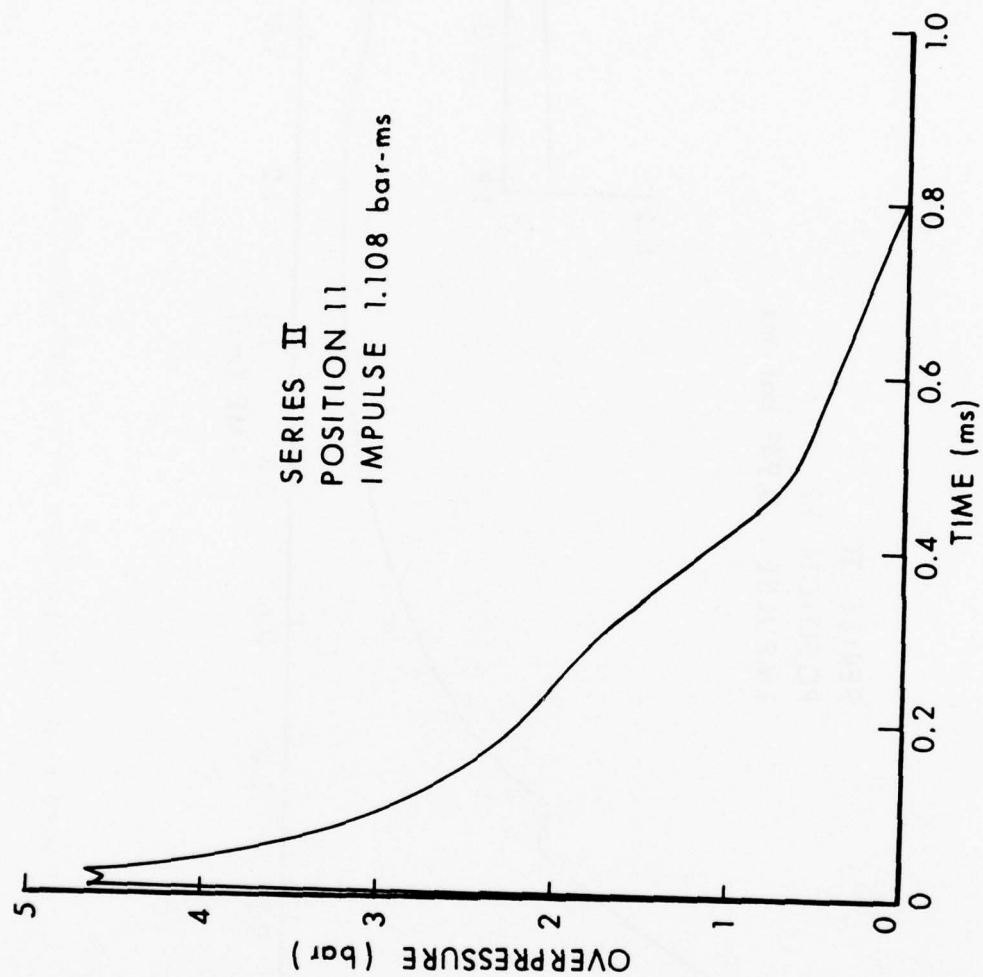
Figure B-9. Overpressure versus Time, Position 11

SERIES II
POSITION 12
IMPULSE 0.941 bar-ms
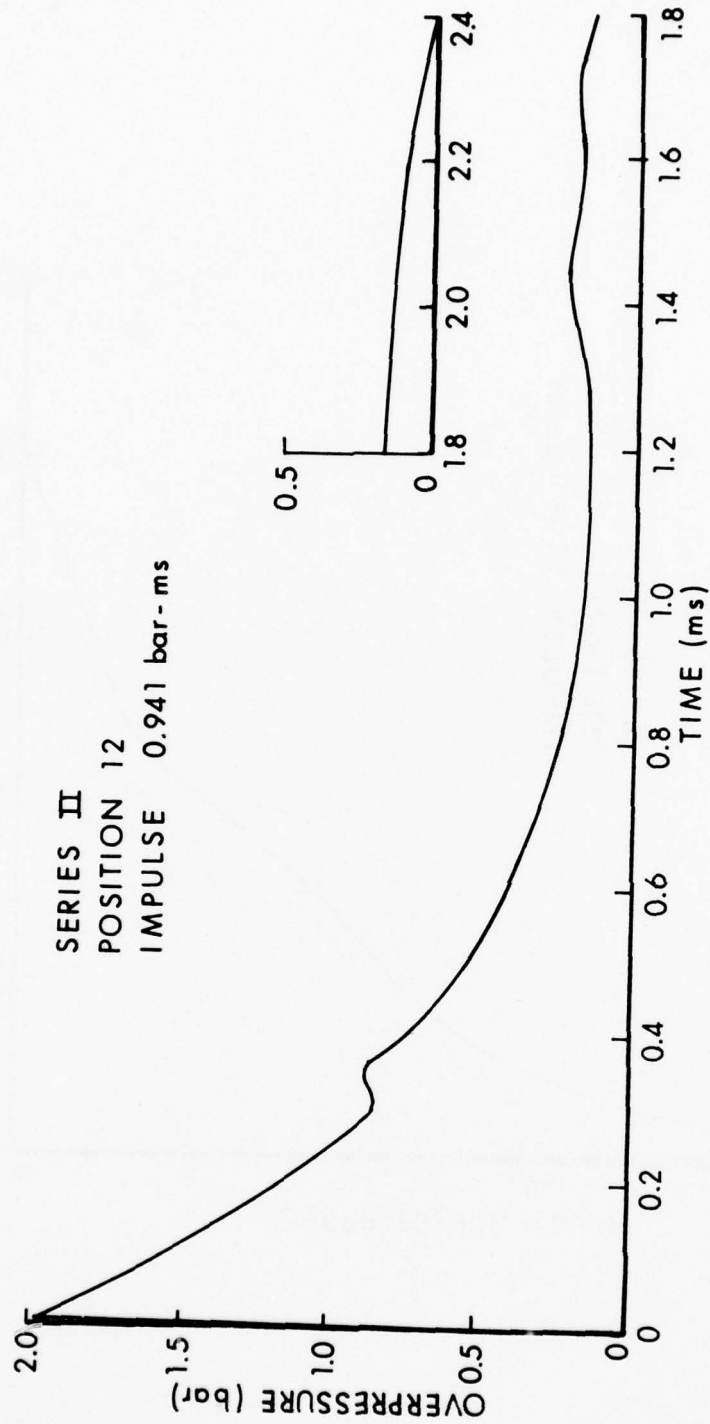
Figure B-10. Overpressure versus Time, Position 12

94

SERIES II
POSITION 13
IMPULSE 1.001 bar-ms

OVERPRESSURE (bar)

TIME (ms)
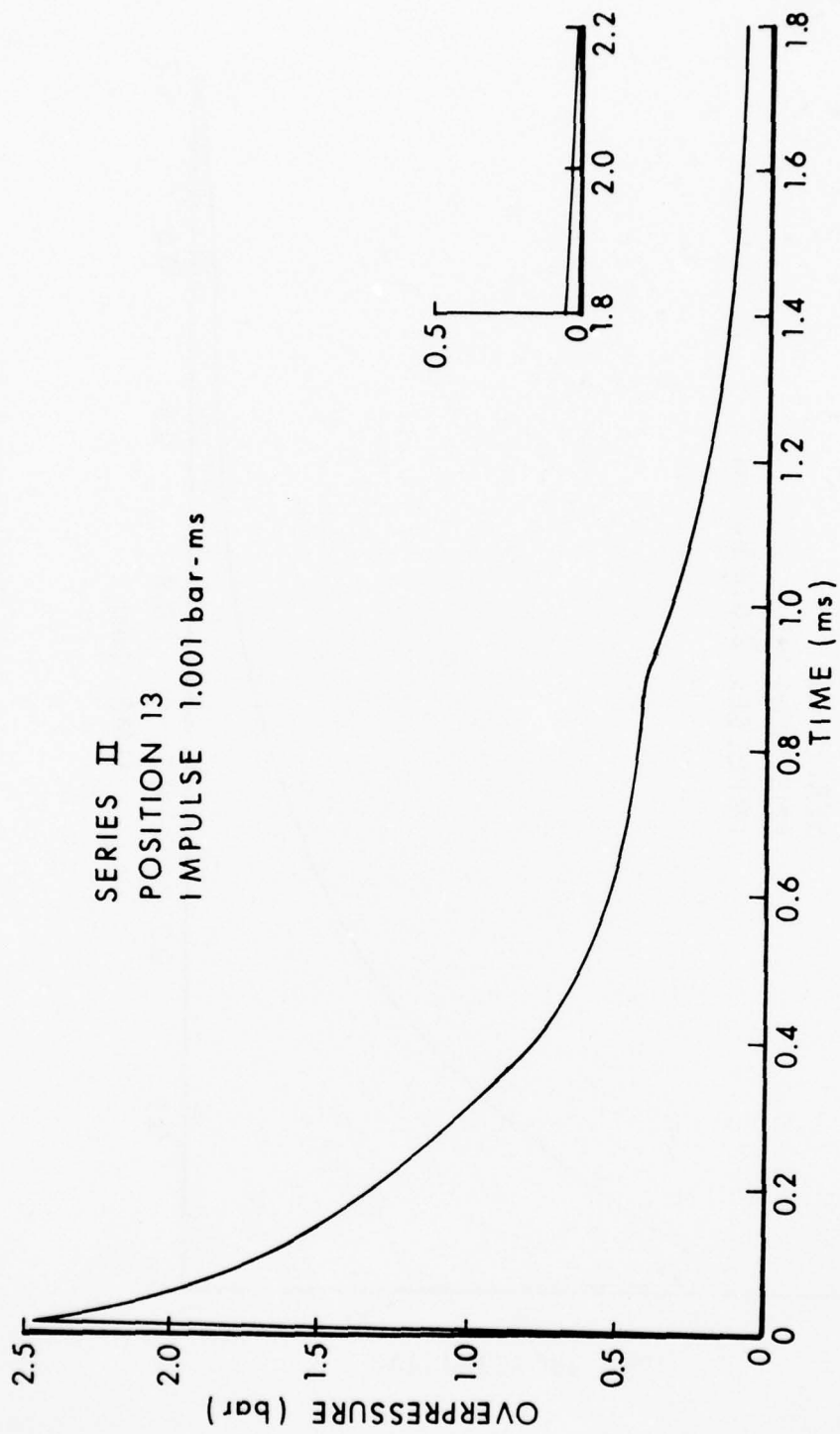
Figure B-11. Overpressure versus Time, Position 15

95

SERIES II
POSITION 14
IMPULSE 2.614 bar-ms

OVERPRESSURE (bar)

20

15

10

5

0
0   0.1   0.2   0.3   0.4   0.5   0.6   0.7

TIME (ms)
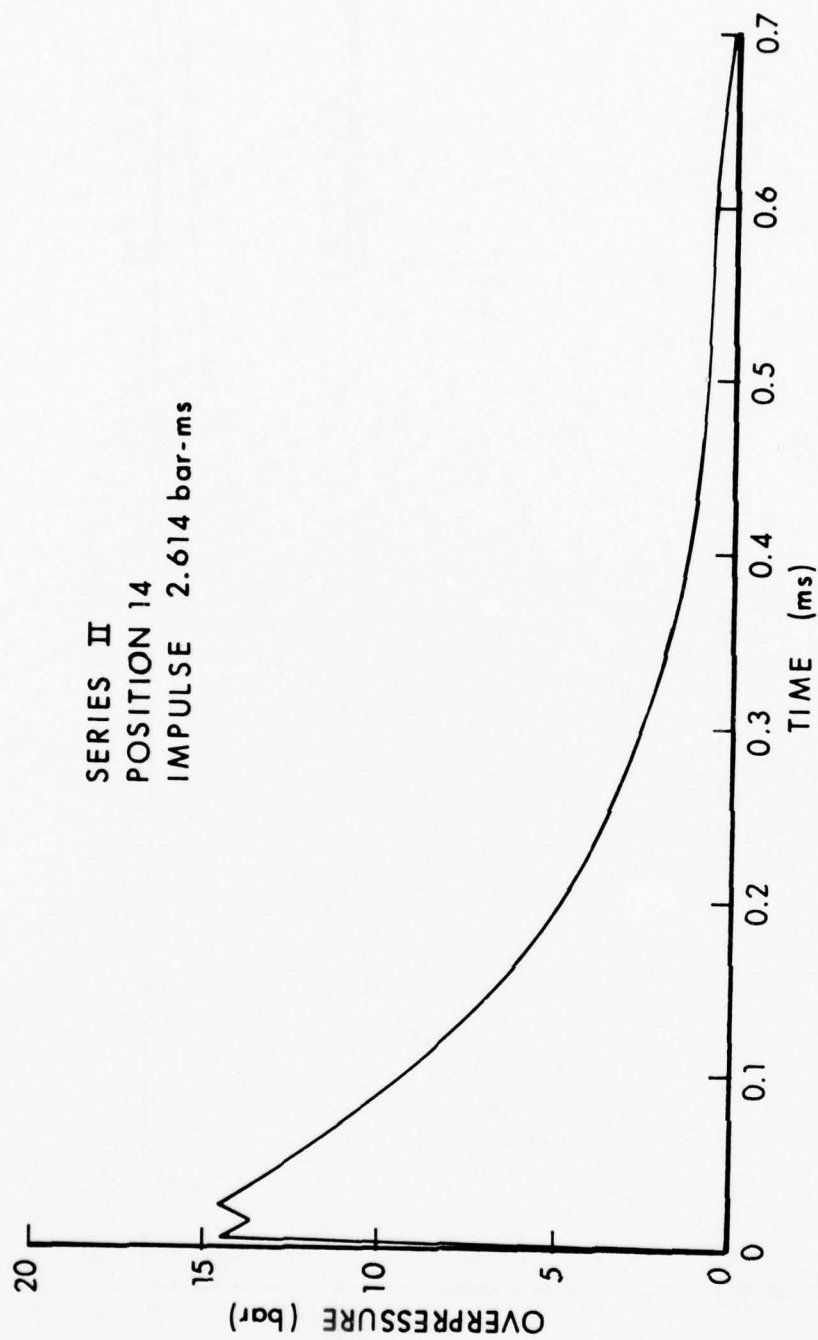
Figure B-12. Overpressure versus Time, Position 14

SERIES II
POSITION 15
IMPULSE 1.399 bar-ms

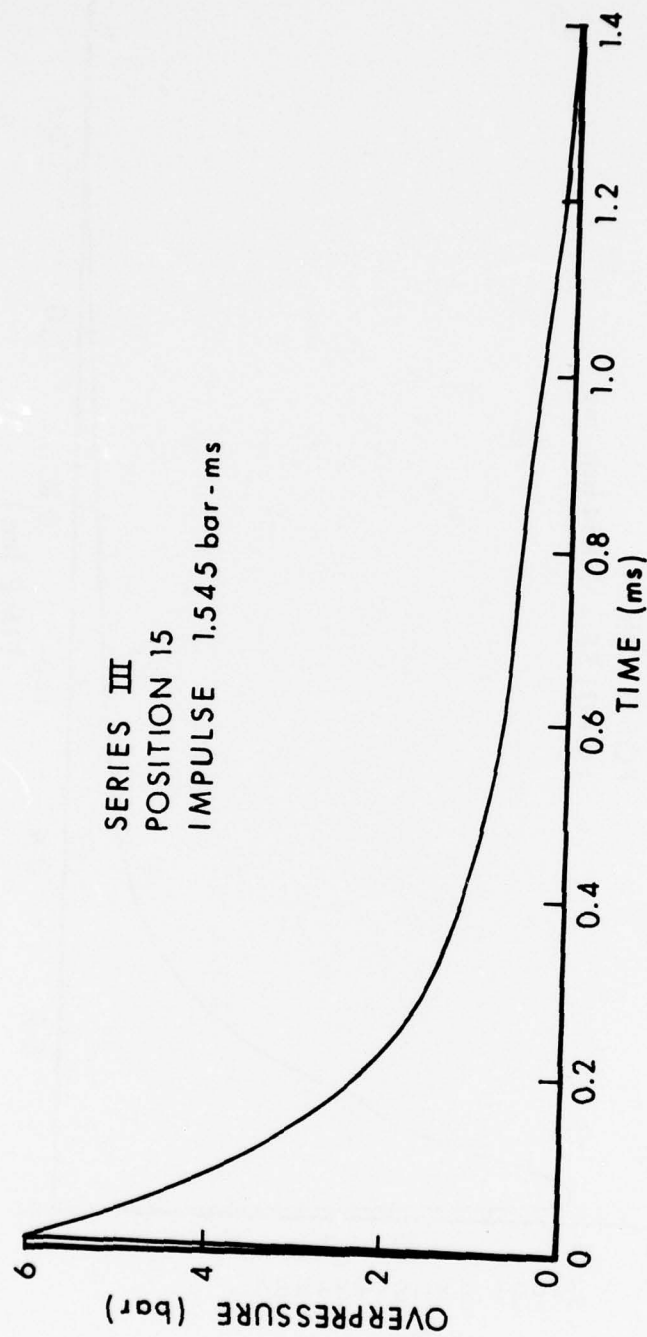OVERPRESSURE (bar)

TIME (ms)

Figure B-15. Overpressure versus Time, Position 15

97

APPENDIX C

Series III - Model Scale 1/30 Charge Weight 1.135 kg Pentolite

APPENDIX C - LIST OF ILLUSTRATIONS

Figure C-1. Overpressure versus Time, Position 1

101
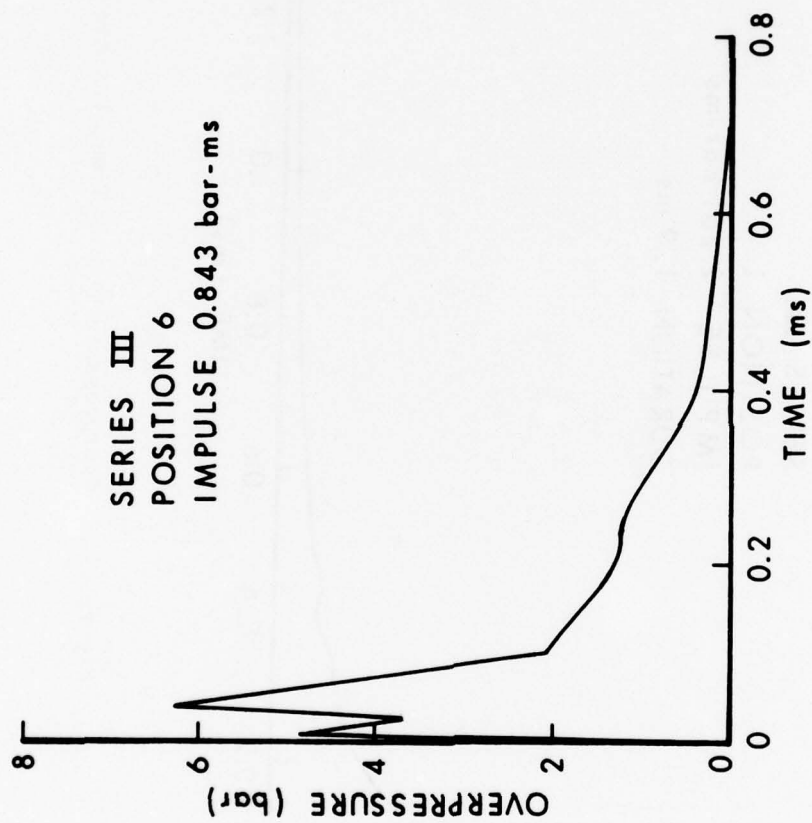
Figure C-2. Overpressure versus Time, Position 6

102

SERIES III
POSITION 7
IMPULSE 1.405 bar-ms
DURATION 1.9 ms
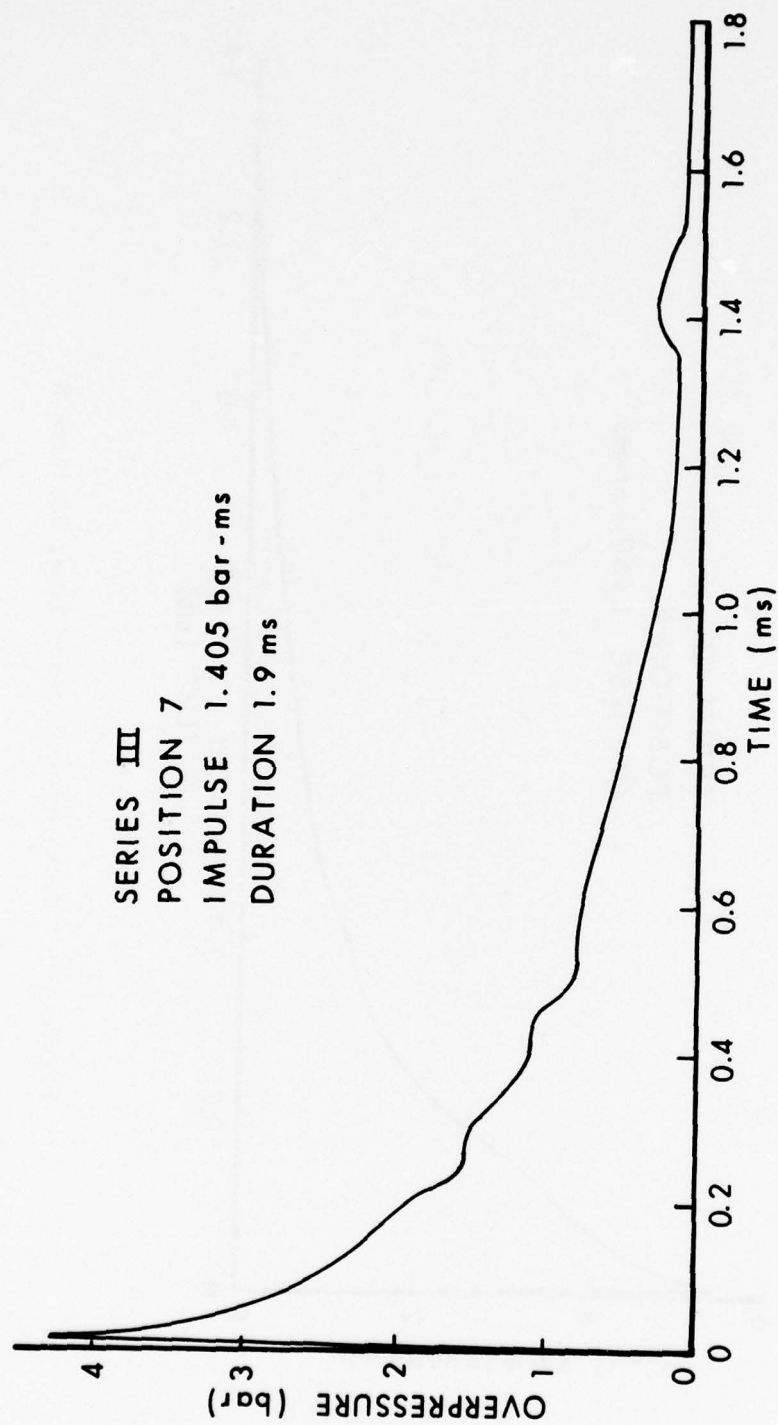
Figure C-3. Overpressure versus Time, Position 7.

SERIES III
POSITION 8
IMPULSE 1.459 bar-ms

OVERPRESSURE (bar)

6

4

2

0

0   0.2   0.4   0.6   0.8   1.0   1.2   1.4

TIME (ms)
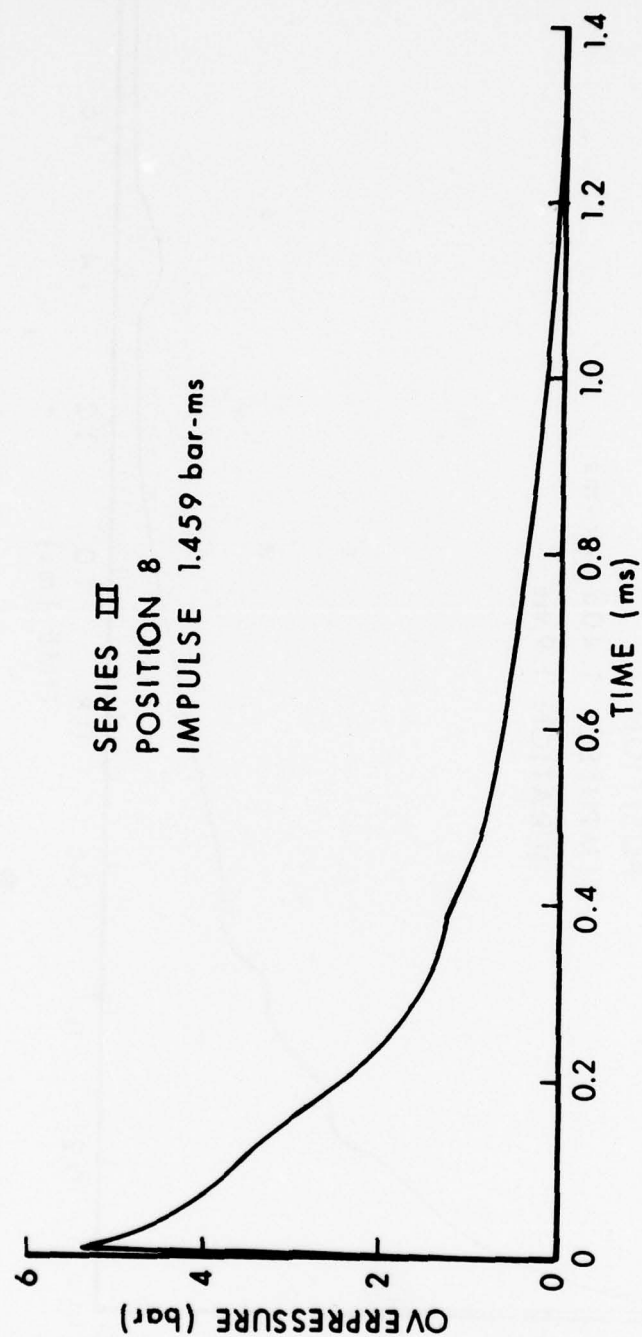
Figure C-4. Overpressure versus Time, Position 8

104

SERIES III
POSITION 10
IMPULSE   1.368 bar-ms
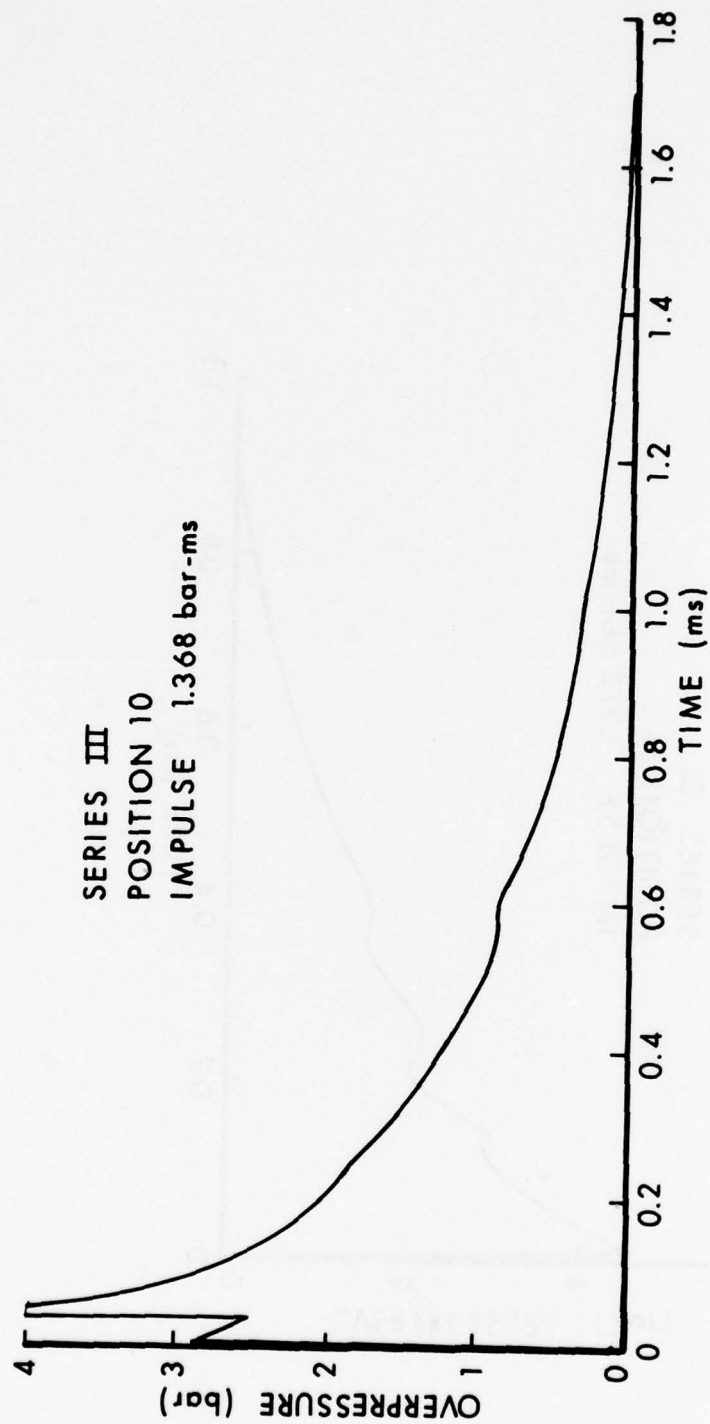
Figure C-5.   Overpressure versus Time, Position 10

105

SERIES III
POSITION 11
IMPULSE 1.373 bar-ms

OVERPRESSURE (bar)

TIME (ms)

Figure C-6. Overpressure versus Time, Position 11

106

SERIES III
POSITION 12
IMPULSE 1.221 bar-ms

Figure C-7. Overpressure versus Time, Position 12

107

SERIES III
POSITION 13
IMPULSE   0.903 bar-ms
DURATION 1.9 ms

OVERPRESSURE (bar)

TIME (ms)

Figure C-8. Overpressure versus Time, Position 15

108

SERIES III
POSITION 14
IMPULSE 2.884 bar-ms

Figure C-9. Overpressure versus Time, Position 14

109

Figure C-10. Overpressure versus Time, Position 15

APPENDIX D

Series VI - Model Scale 1/45 Charge Weight 0.454 kg Pentolite

111

APPENDIX D - LIST OF ILLUSTRATIONS

SERIES IV
POSITION 1
IMPULSE 1.666 bar-ms
DURATION 1.1 ms

Figure D-1. Overpressure versus Time, Position 1

113

SERIES IV
POSITION 2
IMPULSE 2.190 bar-ms
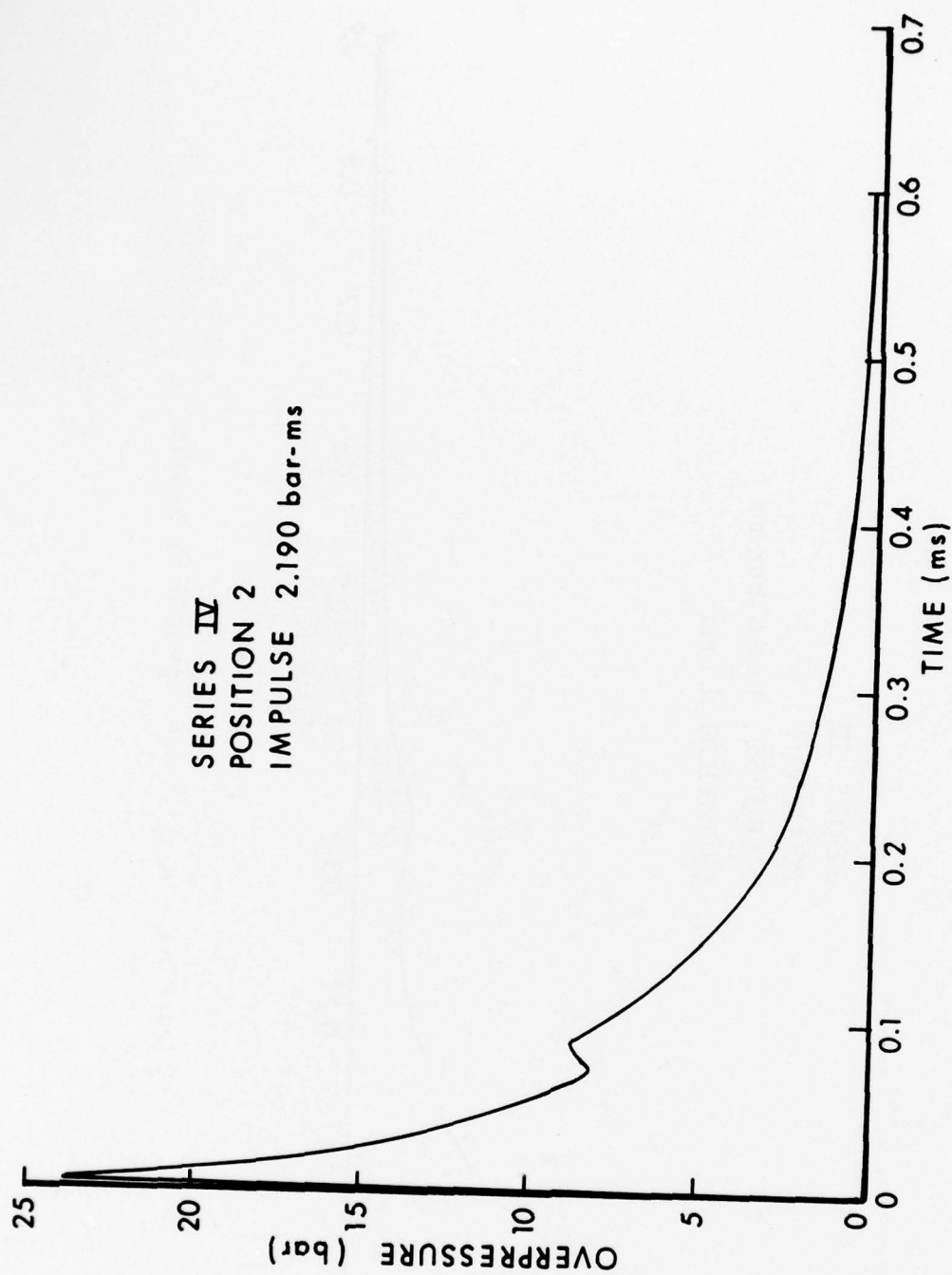
Figure D-2. Overpressure versus Time, Position 2

114

SERIES IV
POSITION 5
IMPULSE 1.683 bar-ms

Figure D-5. Overpressure versus Time, Position 5

SERIES IV
POSITION 6
IMPULSE 0.586 bar-ms

OVERPRESSURE (bar)

TIME (ms)
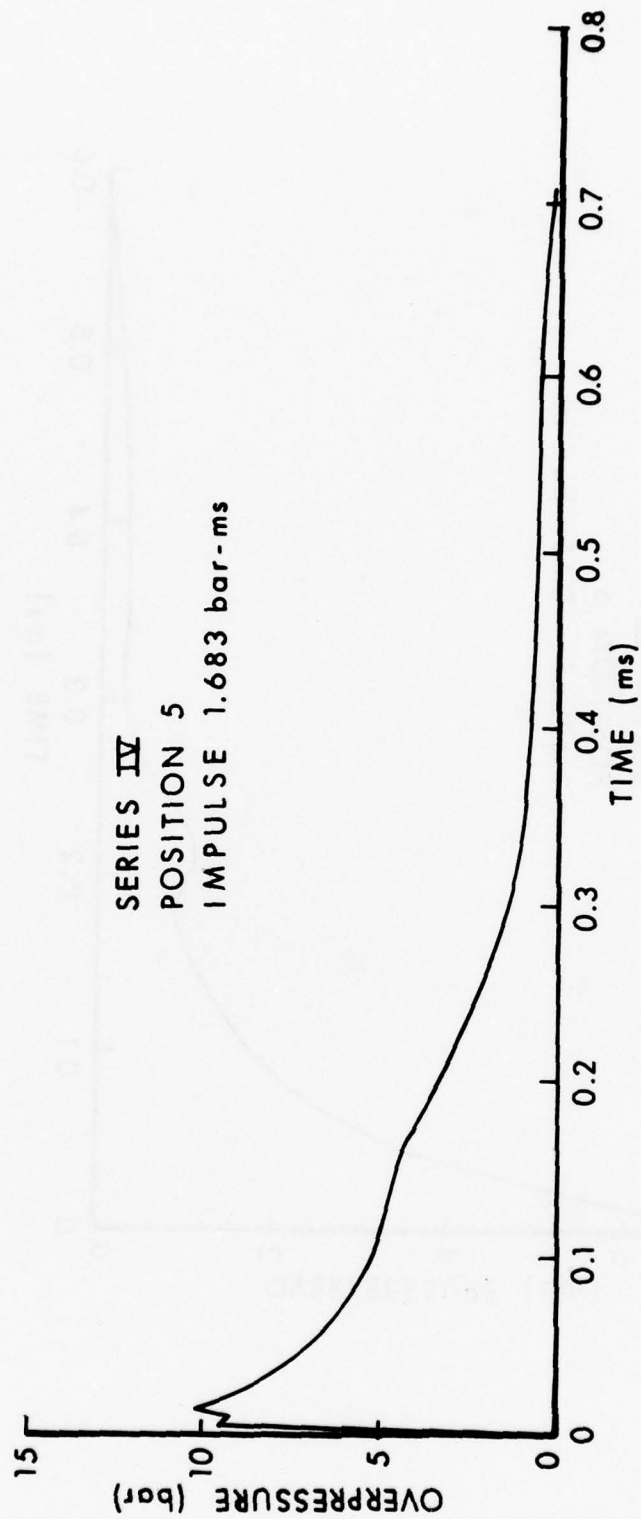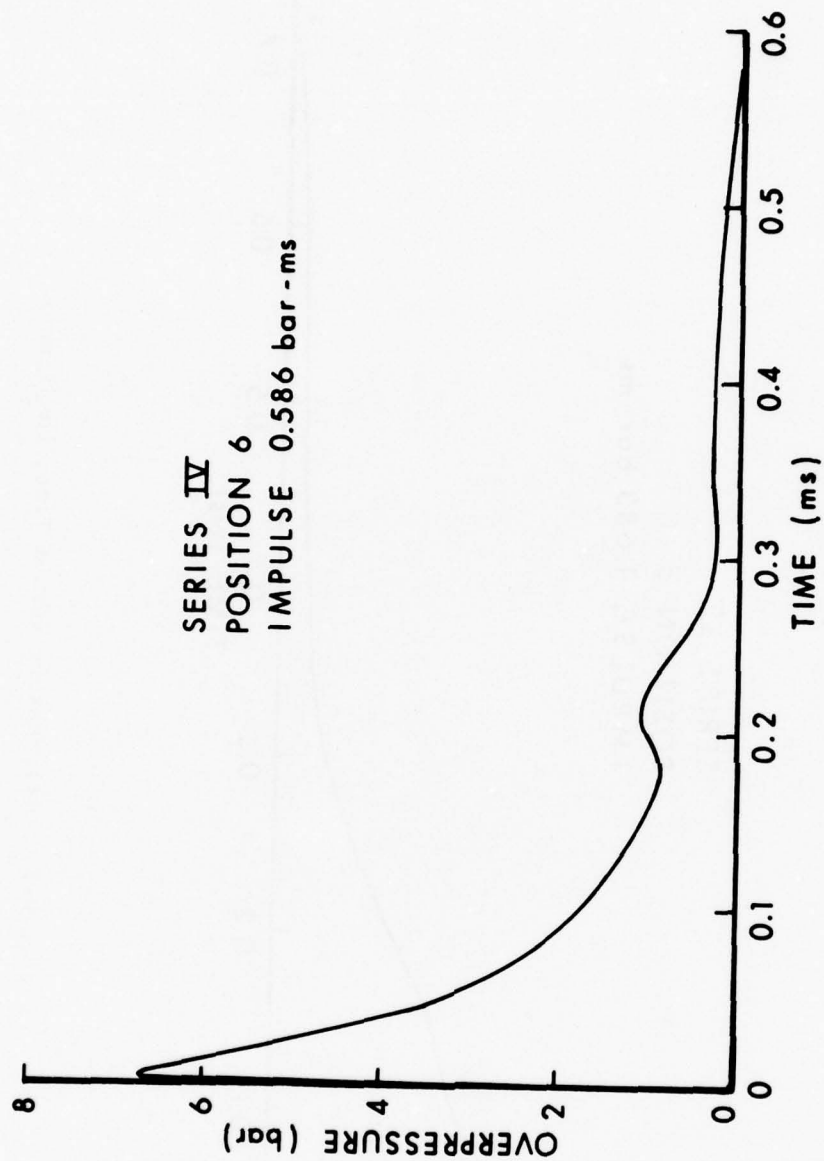
Figure D-4. Overpressure versus Time, Position 6

116

SERIES IV
POSITION 7
IMPULSE 0.956 bar-ms

Figure D-5. Overpressure versus Time, Position 7

117

SERIES IV
POSITION 10
IMPULSE 1.091 bar-ms

OVERPRESSURE (bar)

TIME (ms)
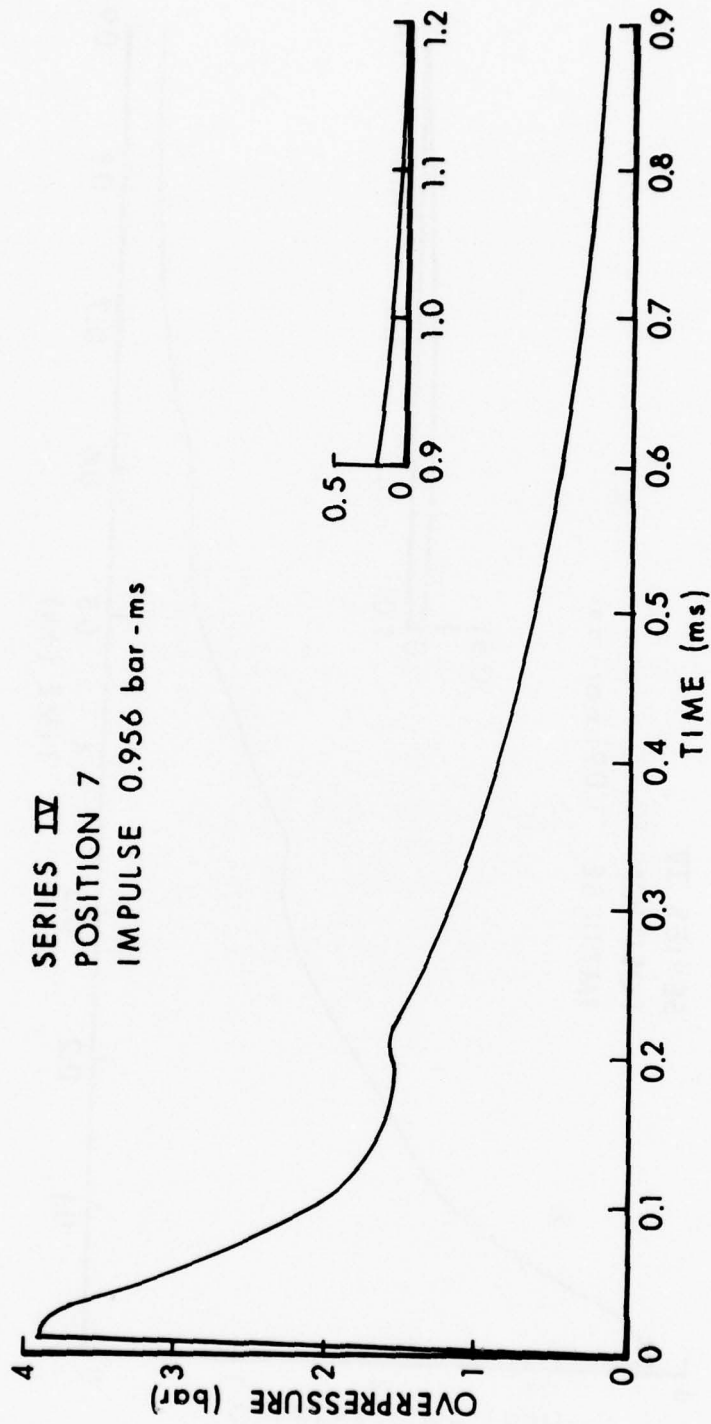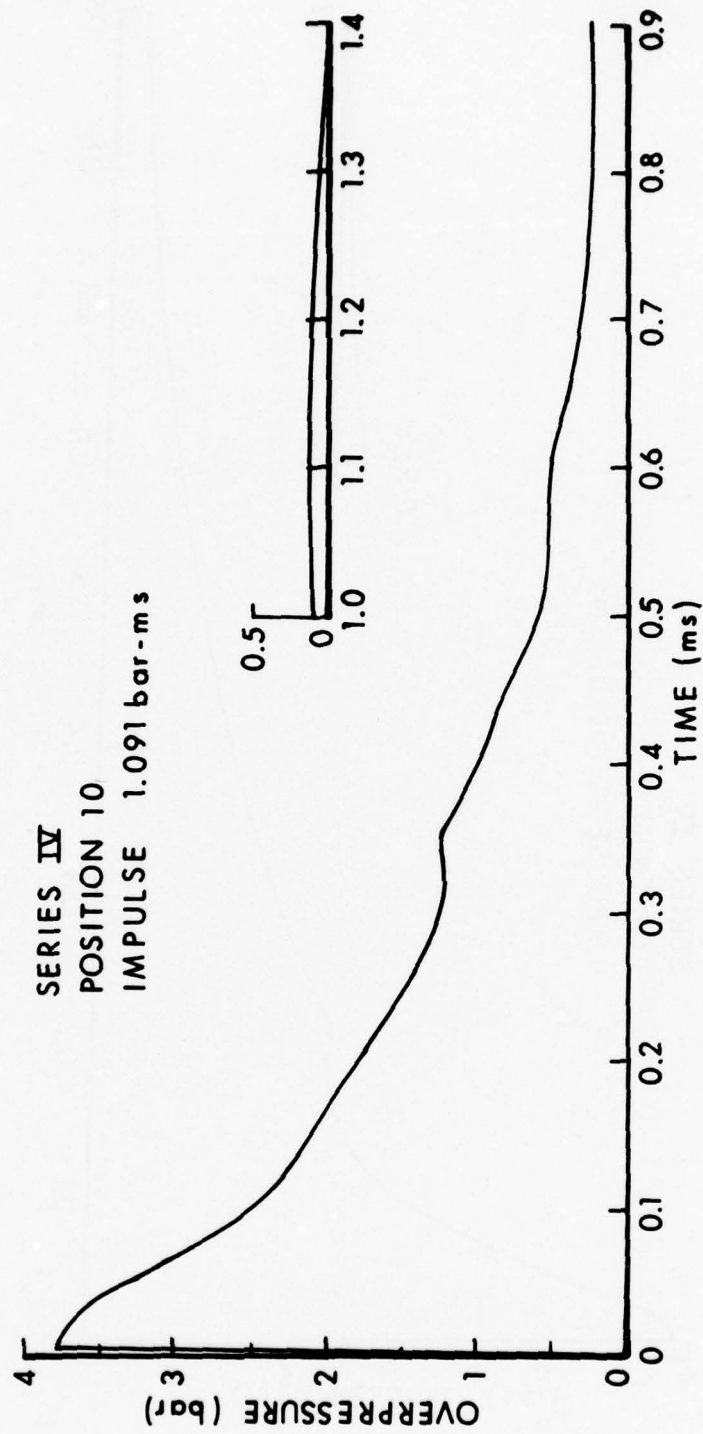
Figure D-6. Overpressure versus Time, Position 10

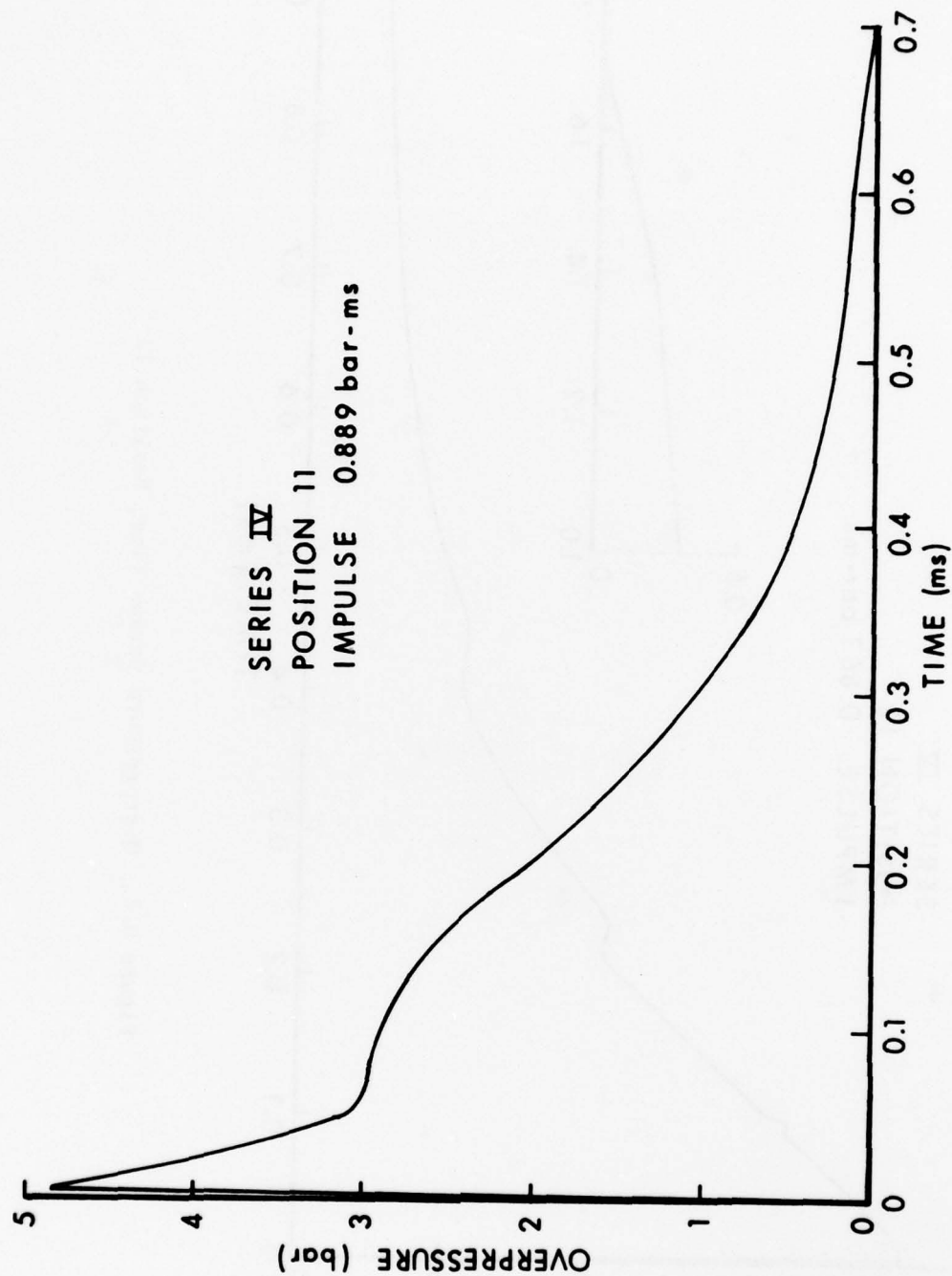118

SERIES IV
POSITION 11
IMPULSE 0.889 bar-ms

OVERPRESSURE (bar)

TIME (ms)

Figure D-7. Overpressure versus Time, Position 11

119

Figure D-8. Overpressure versus Time, Position 12

SERIES IV
POSITION 13
IMPULSE   0.683 bar-ms
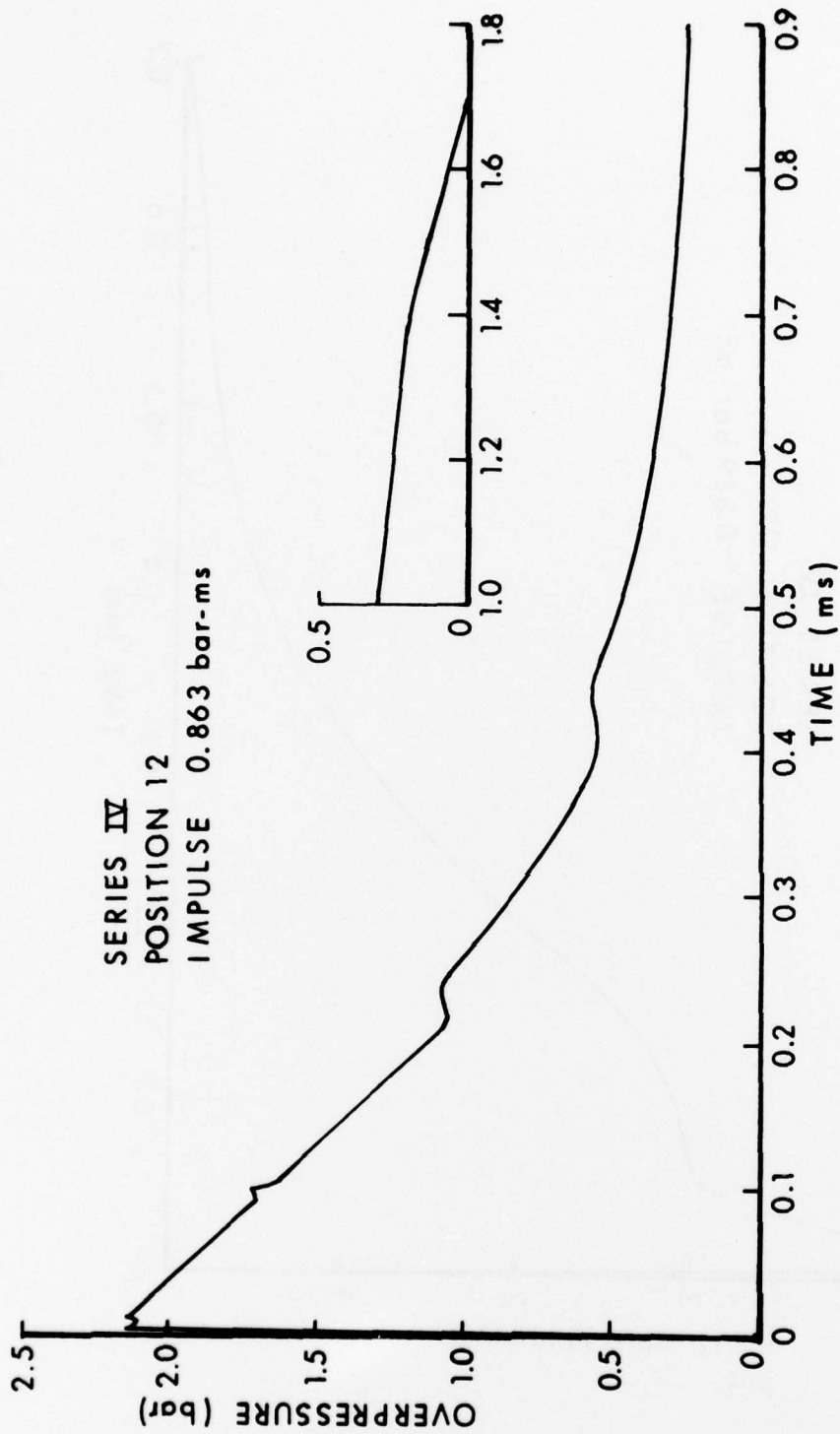
OVERPRESSURE (bar)

TIME (ms)
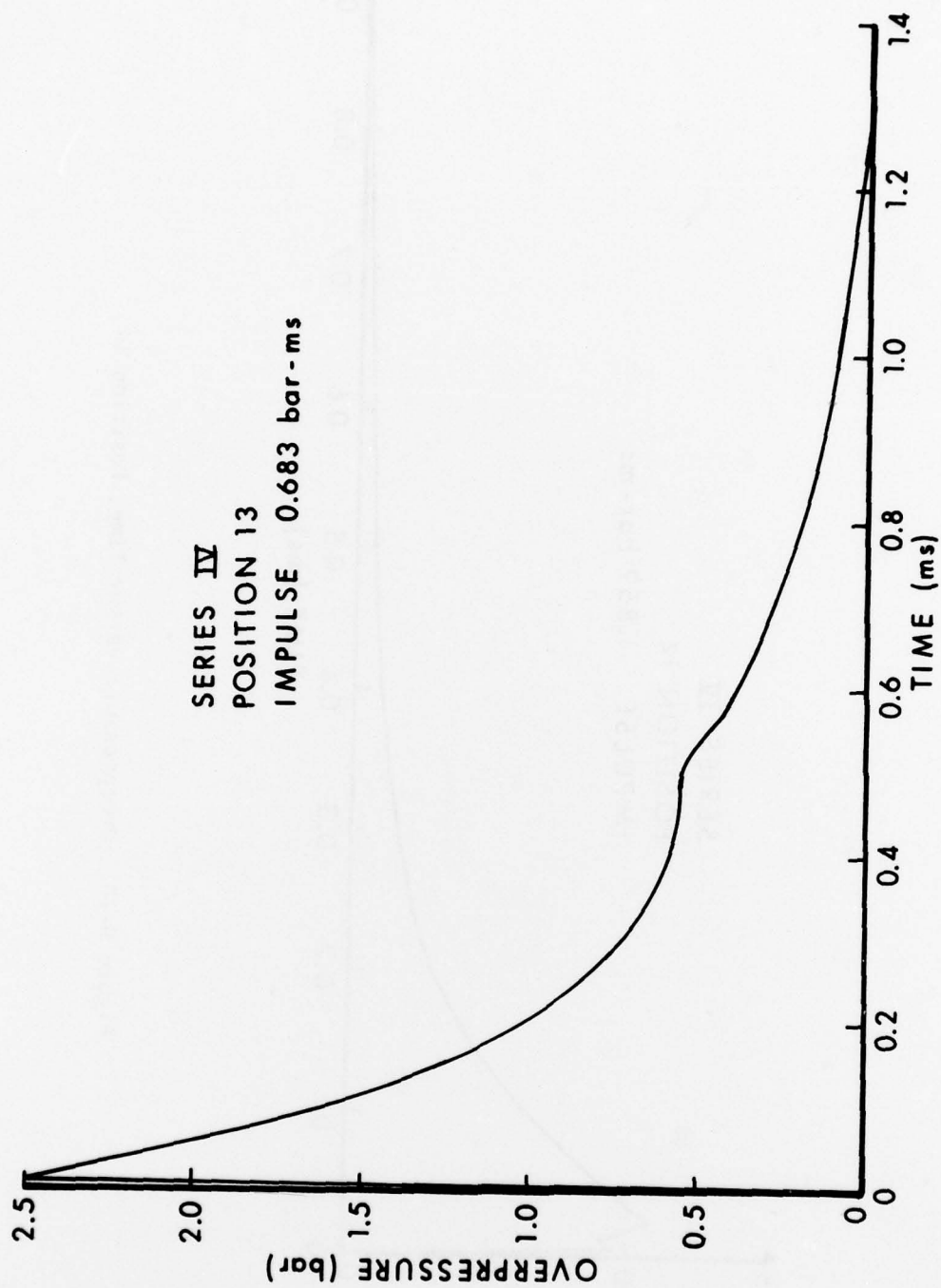
Figure D-9.   Overpressure versus Time, Position 13

Figure D-10. Overpressure versus Time, Position 14

122

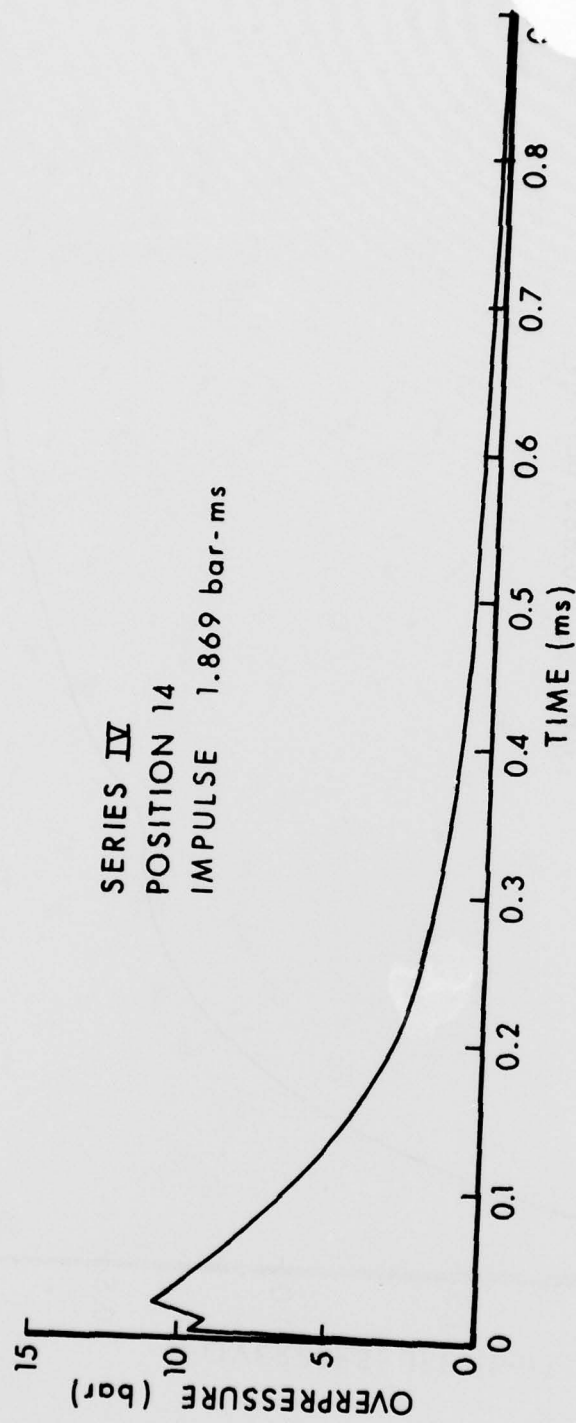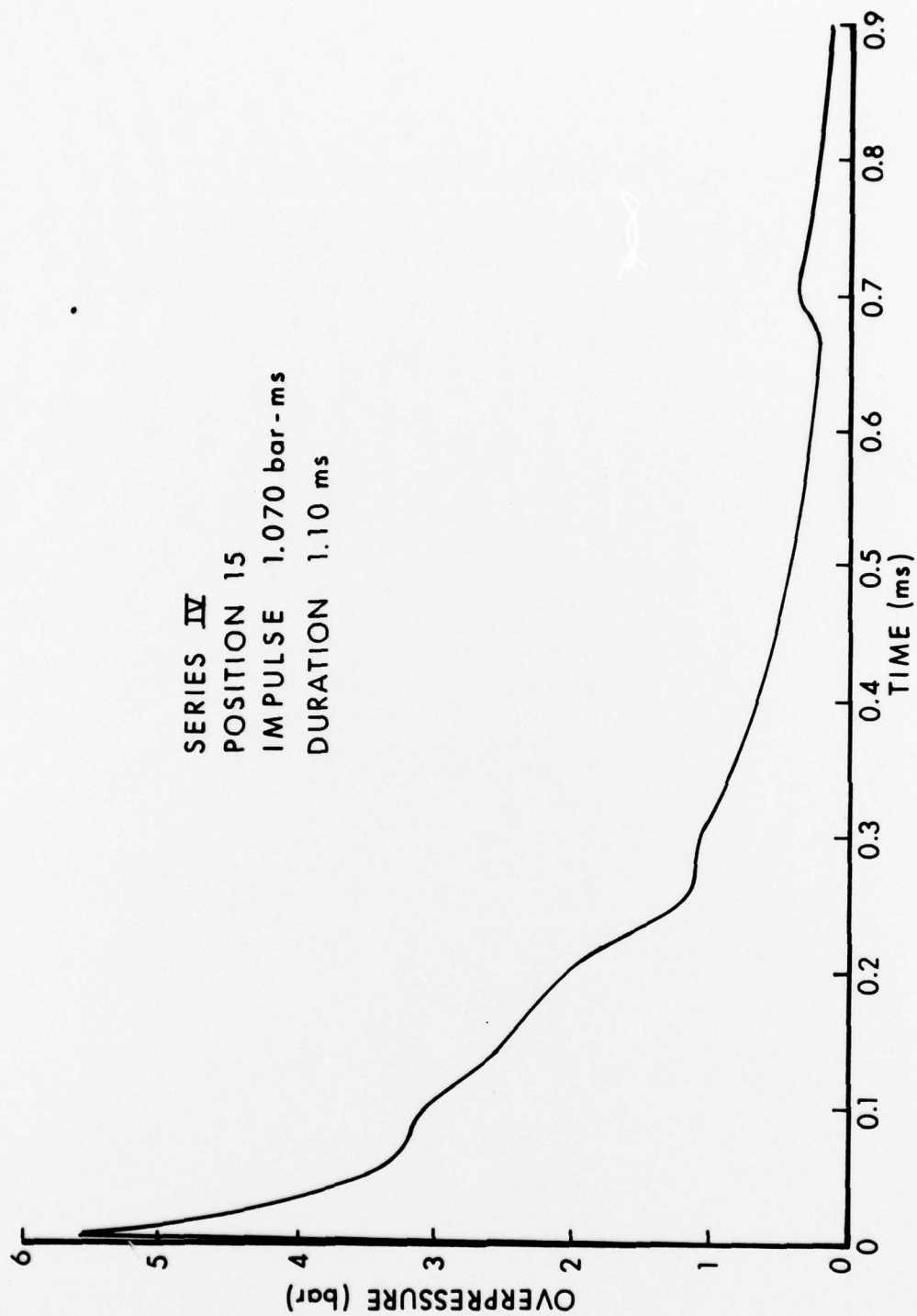SERIES IV
POSITION 15
IMPULSE 1.070 bar-ms
DURATION 1.10 ms

OVERPRESSURE (bar)

TIME (ms)

Figure D-11. Overpressure versus Time, Position 15

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